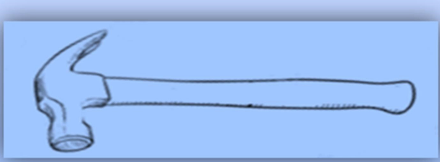
MOBİLYA ve AHŞAP MALZEME ARAŞTIRMALARI DERGİSİ



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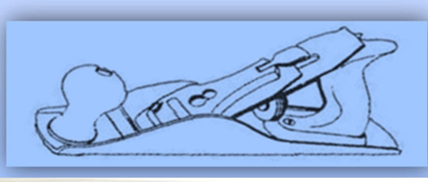

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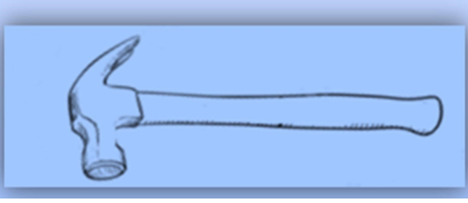

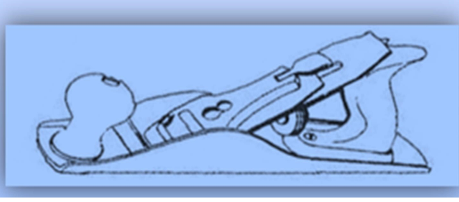

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Ahşap sandalyelerde ara kayıt elemanı kesit ölçüleri ve lokasyonunun mukavemet üzerindeki etkilerinin deneysel ve nümerik analizi

Ali Kasal[1], İbrahim Sedat Yavuz [1], Tolga Kuşkun[1]*

ÖZ: Bu çalışmada, yan çerçevelerinde ara kayıt elemanı olmayan ve farklı kesit ölçüleri ve lokasyonlarda ara kayıt elemanı barındıran ahşap sandalyelerin önden arkaya yükleme altındaki performansları deneysel ve nümerik olarak incelenmiştir. Sandalyelerin üretiminde Türkiye mobilya endüstrisinde yaygın olarak kullanılan Sarıçam (*Pinus sylvestris* L.) tercih edilmiştir. Sandalyelerin yan çerçevelerinde, ara kayıt elemanı için farklı kesit ölçüleri ve lokasyonlar kullanılmış olup en uygun kesit ölçüleri ve lokasyon belirlenmiştir. Birleştirmelerde polivinilasetat (PVAc) tutkalı kullanılmıştır. Buna göre, 3 farklı kesit ölçüsü, 2 farklı lokasyon, ara kayıtsız kontrol örneği ve her örnekten 3 yineleme olmak üzere toplam 21 adet gerçek ölçülerde ahşap sandalye hazırlanmış ve devirli yükleme metoduna göre önden arkaya yönde test edilmiştir. Daha sonra, bilgisayar destekli üç boyutlu nümerik analizler yapılmış ve yan çerçeve birleştirmelerindeki moment dağılımları ve eğilme gerilmeleri analiz edilmiştir. Çalışmanın sonuçlarına göre; ara kayıt elemanının varlığı ve kesit ölçülerinin artması önden arkaya kuvvet taşıma kapasitesini ortalama %48 artırmıştır. Bununla birlikte, ara kayıt elemanının yerden yüksekliğinin 100 mm'den 200 mm'ye çıkarılmasının ise mukavemet değerlerinde sadece %5 artış sağladığı görülmüştür. Ayrıca, nümerik analizlerden elde edilen sonuçların, gerçek deneylerdeki deformasyon karakteristikleri tutarlı olduğu görülmüştür.

Anahtar kelimeler: Sandalye, Mobilya Performans Testleri, Nümerik Analiz

Experimental and numerical analysis of effects of the cross section size and location of stretcher on the strength of wooden chairs

ABSTRACT: In this study, performance of wooden chairs without stretcher in their side frames and containing stretcher in different cross section sizes and locations was investigated experimentally and numerically. In preparing of chairs, Scotch pine (*Pinus sylvestris* L.), which is widely used in Turkish furniture industry was utilized. In the side frames, different cross section sizes and different locations were used for stretcher and the most suitable cross section size and location were determined. Polyvinylacetate (PVAc) was used in gluing. Accordingly, 21 real size chairs were prepared, consisting of 3 cross section sizes, 2 locations, control chair and 3 replications from each, and tested in front to back direction under cyclic loading. Then, numerical analyses were performed and moment distributions and bending stresses in the joints were analyzed. According to results; presence of stretcher and the increase of cross section size increased the loading capacity by average 48%. However, increasing the height of stretcher from 100 to 200 mm from the ground provided 5% increase in strength. It was seen that results obtained from numerical analysis were consistent with experimental failures.

Keywords: Chair, Furniture Performans Tests, Numerical Analysis

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1 Giriş

Mobilya mühendisliği, birçok ülkede olduğu gibi Türkiye'de de hala sistematik bir yaklaşım olarak benimsenmemiş nispeten yeni bir kavramdır. Mobilya elemanlarının tasarımında, birleştirme yöntemlerinin ve bağlantı elemanlarının ölçüleri genellikle estetik kaygılar ve geçmiş tecrübeler doğrultusunda belirlenmiş, matematiksel teorilere dayalı bir analiz yapılmamıştır (Kasal, 2004). Mühendislik süreçlerinin metodolojik olarak uygulanması, mobilyaların sadece estetik ve işlevsel açıdan değil, aynı zamanda dayanıklılık ve güvenlik gibi kriterler açısından da optimize edilmesine olanak tanıyacaktır. Özellikle, malzeme bilimi ve mühendislik analizi sayesinde, mobilyaların kullanım ömrü, dayanıklılığı ve performansı artırılabilir. Sistemin bilimsel bir temele oturtulması, sektörde yenilikçiliği ve kaliteyi teşvik edecek önemli bir adımdır (Efe, 1994; Eckelman, 2003; Kasal, 2004).

Mobilyaların sağlamlığına ilişkin olarak, sandalye yan çerçevelerinde ara kayıt elemanının varlığı, kesit ölçüleri ve lokasyonunun belirlenmesiyle ilgili yapılan çalışmaların sınırlı sayıda olduğu görülmektedir. Masif ve ahşap esaslı levhalardan üretilen koltuk iskeletlerinin performansı deneysel ve nümerik olarak (RISA, 3D) incelenmiş; gerçek deneylerle yapısal analizlerden elde edilen sonuçların tutarlı olduğu, ayrıca koltuk iskeleti üretiminde ahşap esaslı levhaların kullanılabileceği belirtilmiştir (Kasal ve ark., 2006). Endüstriden tesadüfi yöntemle temin edilen farklı modellerdeki sandalyelerin performans test sonuçlarıyla ciddi bir veri tabanı elde edilmiş ve aynı amaç için üretilen sandalye modelleri arasında önemli mukavemet farklılıkları olduğu belirlenmiştir (Efe ve ark., 2015). Farklı ara kayıt konumlarındaki sandalye yan çerçevelerinin sonlu elemanlar analizinin COSMOSWorks programında yapıldığı çalışmada; sonlu elemanlar modellerinin gerçek deneylerden elde edilen davranışa yakın değerler verdiği, ayrıca sandalye yan çerçevelerinde ara kayıt elemanı kullanımının gerilme ve deformasyonları azalttığı bildirilmiştir (Yılmaz ve Güntekin, 2015). Aydın ve Aydın (2017) yaptıkları çalışmada, farklı enine kesit ölçülerindeki sandalye yan çerçevelerini sonlu elemanlar metoduyla CATIA programında analiz etmişler, sonuç olarak enine kesit ölçülerinin yük taşıma kapasitesinde etkili olduğunu vurgulamışlardır. Hu ve ark., (2018), zıvanalı birleştirilmiş bir sandalyede ara kayıt elemanının pozisyonu için optimizasyon çalışması yapmışlar; sonuçta, yük taşıma kapasitesi ile ara kayıt pozisyonu arasında önemli bir ilişki olduğunu bildirmişlerdir. Endüstriyel sandalye tasarımında estetik ve dayanıklılık optimizasyonunun yapıldığı çalışmanın sonuçlarında, piyasadan temin edilen sandalyelerin sağlamlığının, laboratuvarda üretilen tasarım sandalyelerden düşük olduğu, ayrıca endüstriyel sandalyelerin ergonomik açıdan da sorunlu olduğu belirtilmiştir (Küreli ve ark., 2020). Zıvanalı birleştirmeler için alt tolerans sınırları yöntemiyle kabul edilebilir tasarım değerlerinin araştırıldığı çalışmada, birleştirmelerin tasarım değerlerinin bilinmesi durumunda standartlarda belirtilen yükler altında meydana gelebilecek deformasyonların önlenebileceği bildirilmiştir (Uysal ve Haviarova, 2021). Bir başka çalışmada, yarı-rijit birleştirmeli temsili bir sandalye yan çerçevesinde, yarı rijitlik katsayıları ve deplasmanlar arasındaki ilişkiler açı yöntemiyle analiz edilmiş ve açı yönteminin ahşap mobilya çerçevlerinin analizinde kullanılması önerilmiştir (Güray ve ark., 2022). Isıl işlem görmüş ve görmemiş ağaç malzemelerden hazırlanan ve tel zımbalı mobilya birleştirmelerinin statik ve devirli eğilme yükleri altındaki mekanik performanslarının karşılaştırıldığı çalışmada; statik yüklemenin devirli yüklemeye oranı 2,85 olarak elde edilmiştir (Demirel ve Er, 2022). Uysal (2023), ahşap sandalyelerin önden-arkaya devirli yükleme testlerinde, stiffness metodu kullanarak yapısal analizler gerçekleştirmiş ve sonuçta birleştirmeler için kabul edilebilirlik katsayıları önermiştir. Ceylan ve ark., (2024) tasarladıkları farklı tiplerdeki auksetik kavelaların çerçeve konstrüksiyonlu mobilya birleştirmelerinde kullanılm olanaklarını araştırmışlar ve auksetik kavelaların direk çekme mukavemetlerini belirlemişlerdir.

Bu çalışmada, farklı ölçülerdeki ve lokasyonlardaki ara kayıt barındıran ve ara kayıt elemanı bulundurmayan çerçeve konstrüksiyonlu sandalyelerin önden arkaya yükleme altındaki performansları deneysel olarak, birleştirme noktalarında meydana gelen moment değerleri de sonlu elemanlar metoduyla çalışan bilgisayar destekli yapısal analizlerle nümerik olarak elde edilmiştir. Çalışmanın yenilikçi ve özgün yönü, mobilya mühendisliğinde sonlu elemanlar metoduyla, bilgisayar destekli üç boyutlu nümerik analizlerin gerçekleştirilmesi ve özellikle de sandalye birleştirmeleri için literatürde çok sınırlı çalışılmış olan ara kayıt elemanın en uygun kesit ölçülerinin ve lokasyonunun deneylerle belirlenecek olmasıdır. Bu bağlamda, çalışmanın hipotezi, “sandalye yan çerçevelerinde, ara kayıt elemanının varlığının, kesit ölçülerinin ve lokasyonunun sandalyenin mukavemeti üzerinde etkisi vardır” olarak belirlenmiştir.

2 Materyal ve Metot

2.1 Ağaç malzemenin fiziksel ve mekanik özelliklerinin belirlenmesi

Deney örneklerinin hazırlanmasında, Türkiye mobilya endüstrisinde yaygın olarak kullanılan Sarıçam (*Pinus sylvestris* L.) kullanılmıştır. Sarıçam genellikle ev içi kullanımlar yerine restoran vb. gibi mekanlarda enine kesitleri daha büyük, kaba görünüşlü ve oturma elemanlarının üretiminde kullanılmaktadır. Bu ağaç türünden üretilen oturma elemanları daha kolay deforme olmakta ve dolayısıyla yaşam ömürleri de daha kısa olmaktadır. Bu ağaç türünün sandalye üretiminde kullanım imkanlarının deneysel ve nümerik olarak incelenmesi adına, bu çalışmadaki deneylerde Sarıçam odunu tercih edilmiştir. Ağaç malzemeler, rastgele bir yöntemle İzmir’deki kereste işletmelerinden temin edilmiştir. Mobilya mühendisliği tasarım sürecinin ilk aşaması, üretimde kullanılacak malzemelerin fiziksel ve mekanik özelliklerinin belirlenmesidir. Bu doğrultuda, deney örneklerinin üretimi için kullanılan Sarıçam malzemesinin bazı temel fiziksel ve mekanik özellikleri belirlenmiştir. Çalışma kapsamında, kullanılacak malzeme için sırasıyla yoğunluk ve rutubet oranı tayini (TS ISO 13061-1, TS ISO 13061-2), eğilme direnci ve elastikiyet modülü (TS ISO 13061-3, TS ISO 13061-4) deneyleri yapılmıştır.

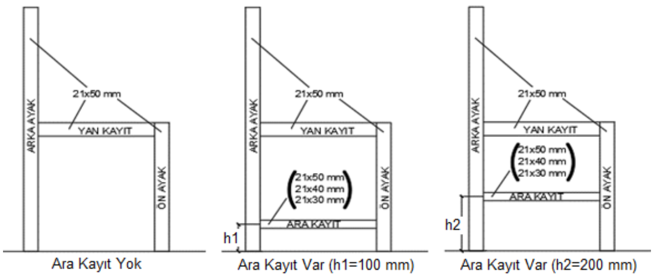
2.2 Deney sandalyelerinin hazırlanması

Deney örneği olarak, toplam 21 adet 1/1 ölçekli deney sandalyesi geleneksel yöntemler ile (atölye tipi) üretilmiştir. Çalışmada, deney sandalyelerinin yan çerçevelerinin üretiminde 3 farklı varyasyon oluşturulmuştur. Bunlar, ara kayıtsız, ara kayıt ekseni yerden 100 mm yukarda ve ara kayıt ekseni yerden 200 mm yukarda olacak şekildedir. Buna göre, yan çerçevedeki ara kayıt elemanının varlığı ve lokasyonunun sandalyelerin mukavemeti üzerindeki etkisi incelenmiştir. Ayrıca, yan çerçevede kullanılan ara kayıt elemanlarının kesit ölçülerinde de 3 farklı varyasyon kullanılmıştır. Deneyler için, 21 x 30, 21 x 40 ve 21 x 50 (radyal x teğet) olmak üzere 3 farklı kesiti ölçüsüne sahip ara kayıt elemanı bulunduran sandalyeler üretilmiştir. Ara kayıt elemanının kesit ölçülerinde genişlik (b) 21 mm olarak sabit tutulmuş, yükseklik (h) ise 30, 40 ve 50 mm olacak şekilde 3 farklı ölçüde kullanılmıştır. Ara kayıt dışındaki tüm elemanların kesit ölçüleri 21 x 50 mm kesit ölçülerinde yapılmıştır. Sandalye elemanlarının üretiminde, kesit yapısında genişlik yönünün radyal, yükseklik yönünün teğet olmasına dikkat edilmiştir. Montaj işlemlerinde, yapıştırıcı olarak Polivinilasetat (PVAc) tutkalı kullanılmıştır. Deney sandalyelerinin üretiminde, yan çerçevelerin oluşturulmasında (ikileme) ön ayak-yan kayıt, arka ayak-yan kayıt, ön ayak-alt ara kayıt ve arka ayak-alt ara kayıt birleştirmelerinde 40 x 40 mm ölçülerinde zıvanalı birleştirme uygulanmış; dörtleme işlemlerinde ise, ön ayak-ön kayıt, arka ayak-arka kayıt ve arka ayak-üst kayıt birleştirmeleri 10 mm çapında ve 35 mm uzunluğunda yivli gövdeli Doğu kayını (*Fagus orientalis* L.) kavela ile gerçekleştirilmiştir. Kavela eksenlerinin kayıt kesitine göre kenara uzaklığı 15 mm, iki kavela ekseni arasındaki mesafe ise 20 mm olarak belirlenmiştir. Kavela delikleri, kavelanın çakıldığı elemanda (kenar) 20 mm, karşı elemanda (yüzey) ise 15 mm derinliğinde açılmıştır; böylece kavela etkili boyu 15 mm olarak hesaplanmıştır. Montaj işlemlerinde presleme yapılırken presleme basıncı ölçülmemiş, ancak presleme basıncında farklılıklar olmaması ve sıkma işlemlerinde aynı derecede basınç uygulanabilmesi adına, kullanılan mengenelerin vidaları sıkıştırma öncesi sonuna kadar gevşetilmiş ve sıkıştırma işlemlerinden sonra da mengenenin hareketli çenesinin vidalama boyunun her bir birleştirme için eşit olmasına özen gösterilmiştir.

Çalışmada kullanılan deneme deseni Çizelge 1'de verilmiş, bu varyasyonlara ilişkin çizimler Şekil 1'de gösterilmiştir.

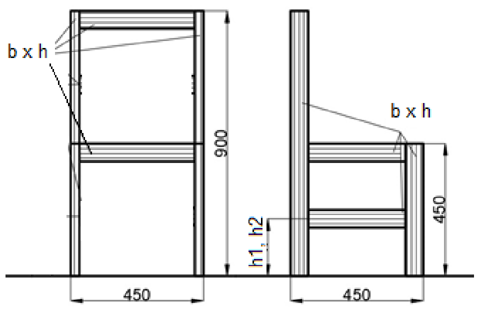
Çizelge 1. Çalışmada kullanılacak deneme deseni

Ara Kayıt Durumu	Ara Kayıt Yerde Yükseklik (h1, h2) (mm)	Ara Kayıt Kesit Ölçüleri b x h (mm)	Yineleme
Ara Kayıt Yok	-	-	3
Ara Kayıt (h1)	100	21 x 30	3
		21 x 40	3
		21 x 50	3
Ara Kayıt (h2)	200	21 x 30	3
		21 x 40	3
		21 x 50	3
Toplam			21

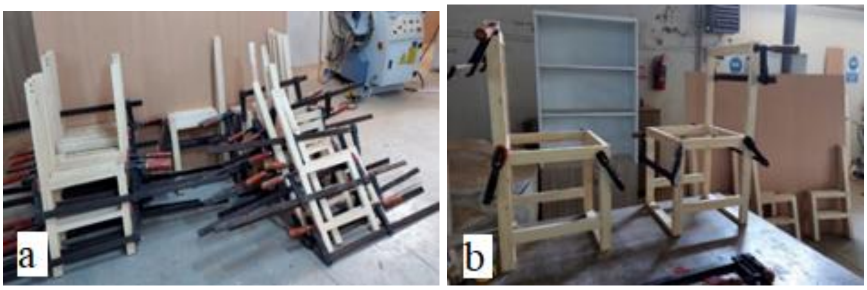


Şekil 1. Sandalyelerin yan çerçevelerinde uygulanan ara kayıt lokasyonu ve kesit ölçüleri

Deney sandalyelerinin net resmi ve genel ölçüleri Şekil 2' de, üretiminde uygulanan ikileme (Şekil 3a) ve dörtleme (Şekil 3b) süreçlerine ilişkin bazı resimler Şekil 3'de verilmiştir.



Şekil 2. Çalışmada kullanılacak deney sandalyesinin genel ölçüleri



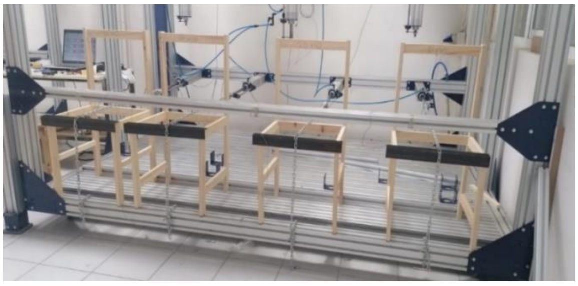
Şekil 3. Deney sandalyelerinin montaj süreçlerinde ikileme (a) ve dörtleme işlemleri (b)

2.3 Deney sandalyelerinin performans testleri

Deney sandalyeleri, American Library Association (ALA, 1982) standartlarına uygun olarak önden arkaya yükleme yönünde, devirli basamaklı artan yükleme metodu ile performans testlerine tabi tutulmuştur. Bu yükleme, mobilyaların günlük kullanımda karşılaşacakları gerçekçi yükleme koşullarını simüle etmeyi amaçlamaktadır. Gerçek kullanımlarda, ürünler belirli bir yükleme düzenine tabi tutulmaz; sistematik olmayan yorma süreçleri sonucunda, malzemenin dayanım sınırları aşıldığında deformasyon meydana gelir. Devirli basamaklı artan yükleme metodu, ürünün kullanım ömrü boyunca karşılaşabileceği çeşitli yükleme ve zorlanmalara karşı dayanımını ölçmek için geliştirilmiştir. Bu yöntem, sistematik olmayan yükleme senaryolarını, belirli ve kontrollü bir döngü içinde uygulayarak, ürünün performansını değerlendirmek için etkili bir araçtır. Yani, ürünün maruz kalacağı rastgele yorma etkilerini, sistematik bir devirli basamaklı yükleme düzeni ile temsil eder.

Önden arkaya yükleme yöntemi, sandalye oturma çerçevesine bir zincir yardımıyla önden arkaya doğru çekme kuvveti uygulanarak, sandalye yapısının bu zorlamaya karşı ne kadar dayanıklı olduğunu test etmeye odaklanır. Bu sayede, özellikle yan çerçevelerdeki birleştirmelerin mukavemeti ölçülür. Deneylerde, önden arkaya doğru dakikada 20 devir olacak şekilde yatay yönde bir yükleme uygulanmıştır. Başlangıç yükü 445 N olarak belirlenmiş ve her başarılı tamamlanan 25.000 devir sonrası bu yük 112 N artırılarak testler sürdürülmüştür. Toplamda 1112 N'luk bir yük değerine ulaşıldığında, yük artış miktarı 112 N'den 224 N'a çıkarılmıştır (ALA, 1982; Eckelman, 1995; Eckelman, 1999).

Şekil 4'te görülen düzenekte, önden arkaya yükleme, pistona kilitli bir şekilde tutturulmuş bir zincir aracılığıyla gerçekleştirilmiştir. Yükleme zinciri, sandalyenin genişlik yönünde tam ortasına yerleştirilmiş ve çekme yükü bu merkezde uygulanan bir piston yardımıyla verilmiştir. Deney sürecinde yüklemeler, sandalye elemanlarında kırılma, birleştirme noktalarının açılması veya aşırı deformasyon gibi dayanım kayıpları oluşana kadar kademeli olarak arttırılmıştır. Deney sonuçlarına göre, sandalyenin kırıldığı andaki devir sayısı ve son 25.000 devri tamamladığı yük değeri, sandalyenin ömrü ve kuvvet taşıma kapasitesi olarak kaydedilmiştir.



Şekil 4. Deney sandalyelerin önden arkaya devirli yükleme testleri

2.4 Bilgisayar destekli nümerik analizler

RISA 3D programı kullanılarak yapılan bilgisayar destekli üç boyutlu yapısal analizlerde, yapı elemanlarının ve sistemin davranışı detaylı şekilde incelenmektedir (RISA 2000). Bu analizde, mesnet noktalarındaki tepki kuvvetleri, elemanlardaki basınç ve çekme kuvvetleri, üç farklı yöndeki (X, Y, Z) kesme ve moment kuvvetleri hesaplanabilmektedir. Ayrıca, elemanlarda kesit özelliklerine göre oluşan basınç ve çekme gerilmeleri ile yine üç yönde meydana gelen kesme ve eğilme gerilmeleri de belirlenebilmektedir. Bunun yanı sıra, her bir düğüm noktasındaki yer değiştirme değerleri ve sistemin genel yer değiştirme durumu da analiz edilebilmektedir.

Deney sandalyeleri, yapısal analizlerde gerçek hayattaki davranışlarına uygun olarak üç boyutlu çerçeve sistemleri şeklinde modellenmiştir. Sandalyeyi oluşturan tüm yapısal elemanlar, doğrusal elastik kirişler olarak kabul edilmiştir. Yani bu elemanlar, eksenel kuvvetleri, kesme kuvvetlerini ve momentleri taşıyabilecek şekilde tanımlanmışlardır. Her bir eleman tanımlanırken ağaç malzemenin yönleri (lif, radyal, teğet) dikkate alınmıştır. Bu yaklaşım, elemanların yükler altındaki davranışını doğru bir şekilde simüle etmek için kullanılmıştır. Modelleme sürecine başlarken, ilk olarak kullanılan birim sistemi ayarlanmıştır. Bu çalışmada, metrik sistem ve SI (Uluslararası Birimler Sistemi) esas alınmıştır. Ardından, sandalyelerin üretiminde kullanılan malzemenin özellikleri programa girilmiştir. Yapısal analizlerde doğru sonuçlar elde edebilmek için, sandalyelerin iskeletlerinde kullanılan Sarıçam malzemesinin bazı teknolojik özelliklerinin programa tanımlanması önemlidir. Bu özelliklerin bir kısmı yapılan deneylerle elde edilirken, bazıları literatürdeki kaynaklardan alınmıştır (USDA, 2021; Güntekin, 2023). Deney sandalyelerinin yapımında kullanılan Sarıçam malzemesinin rutubet oranı ise %10,2 olarak ölçülmüştür. Malzemeleri tanımlamak amacıyla programa girilen bu özellikler Çizelge 2 'de gösterilmiştir.

Çizelge 2. Sarıçam malzemenin programa girilen teknolojik özellikleri

Malzeme	Liflere Dik Eğilmede Elastikiyet Modülü (E_L) (N/mm²)	Rijitlik (Kayma) Modülü (G_{LR})(N/mm²)	Poisson Oranı (μ)	Isı İletkenliği Katsayısı (W/m.K)	Yoğunluk (kg/m³)	Liflere Dik Eğilme Direnci (σ_e) (N/mm²)
Sarıçam	10289	1334*	0,72*	0,13**	450	99

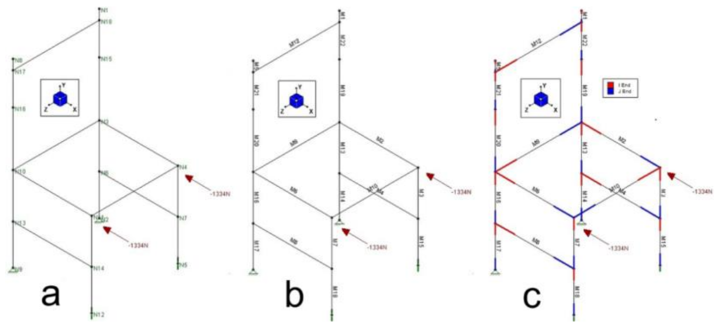
*: Güntekin (2023)'ten alınmıştır, **: USDA (2021)'den alınmıştır.

Bu aşamadan sonra, sandalyeyi oluşturan elemanlarının kesit özelliklerinin tanıtılması yapılmıştır. Sandalyelerde, modellenen tüm elemanların kesit ölçüleri 21x50 mm ölçülerinde olup sadece yan çerçevelerindeki alt ara kayıtın ölçülerinde sandalye tipine göre farklılıklar (21x30, 21x40 ve 21x50 mm) vardır. Ayrıca, bir sandalye tipinde de yan çerçevelerde ara kayıt elemanı yoktur. Buna göre, kesit ölçüleri tanımlanırken, sandalyenin tüm elemanları 21x50 mm, yan çerçevelerdeki ara kayıt elemanları ise sandalye tipine göre uygun kesit ölçülerine sahip olacak şekilde tanımlanmıştır (Çizelge 3). Eylemsizlik momenti; "$I=b \times h^3/12$" (mm^4), dönme eylemsizlik sabiti "$J=(h/2x(b/2)^3)x((16/3)-3,36x((b/2)/(h/2))x(1-((b/2)^4/(12x(h/2)^4))))$" eşitlikleri ile hesaplanmıştır.

Çizelge 3. Sandalye elemanlarının kesit özellikleri

Kesit ölçüleri (bxh)(mm)	Kesit Alanı (*A=bxh*) (*mm²*)	Eylemsizlik Momenti (I_z) (*mm⁴*)	Eylemsizlik Momenti (I_y) (*mm⁴*)	Dönme Eylemsizlik Sabiti (*J*) (*mm⁴*)
21 x 50	1050	218750	38588	113615
21 x 40	840	112000	30870	82898
21 x 30	630	47250	23153	52586

Sonraki adımda, sandalyelerin tüm elemanları gerçek ölçülerde ve kesit yapısında olacak şekilde modellenmek suretiyle üç boyutlu sandalye modeli oluşturulmuştur. Sandalye modeli üzerinde analiz yapılabilmesi için elemanların kesişme noktalarından birleştirilmesi (kaynaklanması) gerekmektedir. Sandalye elemanları birleştirme işleminden önce uç uca temas halinde olmasına rağmen tam bir birleşme söz konusu değildir. Yapısal analiz yapılabilmesi için her bir elemanın kesişme noktalarından birbiriyle tam olarak birleşmesi gerekir. Birleştirme işleminden sonra modelde kesişen/temas eden noktalar birbirine kaynaklı gibi birleşmiştir. Bu aşamada, sandalye modeli oluşturulmuştur ve sistem tarafından her bir düğüm (birleştirme) noktasına (N1, N2, … Nn) ve sandalye modelini oluşturan her bir elemana (M1, M2, … Mn) kod numaraları verilmiştir. Oluşturulan modellerin düğüm noktaları, elemanları ve elemanların başlangıç (i: Kırmızı) ve bitiş (j: Mavi) noktaları Şekil 5’te gösterilmiştir.



Şekil 5. Düğüm noktaları (a), elemanlar (b) ve başlangıç/bitiş uçları (c)

Eckelman'a (1968) göre, mobilya sistemlerini oluşturan bağlantı noktaları yarı rijit özellik gösterir. Her bir bağlantı noktasının kendine özgü bir elastikiyet değeri vardır. Yapısal analizlerde bu bağlantıların yarı rijit olarak tanımlanması, sistemin gerçek davranışına en yakın sonuçları elde edebilmek açısından büyük önem taşır (Eckelman, 1968). Çalışma kapsamındaki yapısal analizlerde, birleştirme noktaları tanımlanırken, birleştirmelerin tanımlanmasında literatürde geçmiş çalışmalardaki deneylerden elde edilen yarı rijitlik katsayılarından yararlanılmıştır (Ceylan ve ark., 2021). Sandalyelerdeki her bir birleştirme noktası programa yay (spring) olarak tanımlanmış ve yay sabiti değeri olarak da her bir birleştirme için literatürden alınan yarı rijitlik katsayıları (Z) ekseni etrafındaki rotasyonlar olarak bu noktalara tanımlanmıştır (Çizelge 4).

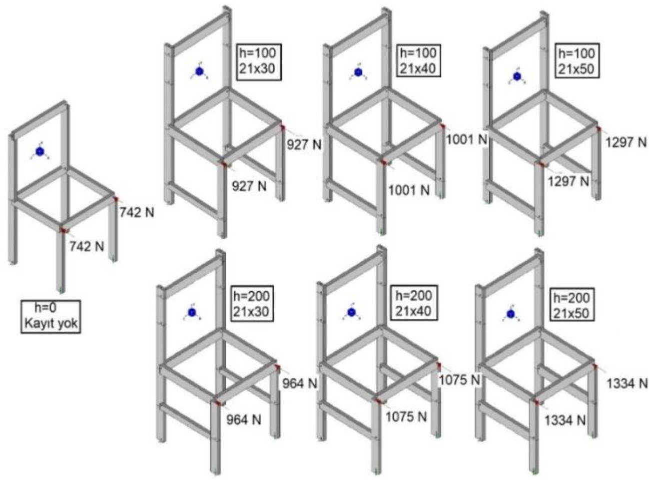
Çizelge 4. Her bir birleştirme için tanımlanan yay sabiti değerleri, K (Ceylan ve ark., 2021)

Ağaç türü	**Yarı Rijitlik Katsayısı (*K*) (*Nm/rad*)**		
	Arka ayak – Yan kayıt	Arka/Ön ayak – Ara kayıt	Ön ayak – Yan kayıt
Sarıçam	2702	916	1247

Yapısal analiz programında modellenmesi tamamlanan 7 farklı sandalyeye ilişkin üç boyutlu görünüşler Şekil 6’da her bir grup sandalye için deneylerden elde edilen ortalama maksimum yük değerleriyle birlikte gösterilmiştir.

Yapısal analizlerin gerçekleştirilmesinde, öncelikle modellenen sandalye ayaklarında mesnetleme işlemleri yapılmış, daha sonra yük uygulama aşamasına geçilmiştir. Gerçek deneylerdeki mesnetlemenin yapılmasında, sandalyenin ön ayak elemanında hareketli, arka ayak elemanında ise sabit (pimli) mesnet kullanılmaktadır. Yapısal analizlerde de mesnet tanımlanırken, sabit mesnet ayarı için arka ayak elemanının düğüm noktası için X, Y, Z yönündeki translasyonlara (öteleme) reaksiyon verilmiş, rotasyonlar ise serbest bırakılmıştır.

Ön ayakta hareketli mesnet ayarı için ise düğüm noktasında sadece Y yönündeki ötelemelere reaksiyon verilmiş, geri kalan tüm öteleme ve rotasyonlar serbest bırakılmıştır.



Şekil 6. Yapısal analiz programında her bir tip sandalyeye ilişkin oluşturulan modeller

Mesnet ayarları yapıldıktan sonra yükün uygulanacağı noktalar, gerçek deneylerdeki uygulama noktalarından olacak şekilde yük uygulama ekseni ve yönü dikkate alınarak uygulanmıştır. Deney sandalyeleri, gerçek deneylerde devirli basamaklı artan yükleme metoduna göre test edilmesine rağmen, bilgisayar destekli üç boyutlu yapısal analizlerde sistem statik yüklemeye göre çözülmüştür. Yapısal analizlerde yükler uygulanırken, statik ve devirli yükler arasındaki ilişki dikkate alınmıştır. Literatürde, devirli yükler altında bir yapının mukavemetinin, statik yükler altındaki mukavemetin %50'sini geçmemesi gerektiği ifade edilmiştir (Erdil, 1998; Eckelman ve Erdil, 1999; Kuşkun, 2013; Likos ve ark., 2012; Kuşkun ve ark., 2018). Bu durumda, bir çerçeve sisteminin devirli yükler altındaki dayanımı, statik yükler altındaki dayanımının yarısı olarak kabul edilmektedir. Dolayısıyla, bilgisayar destekli yapısal analizlerde, gerçek deneylerden elde edilen maksimum kuvvet değerlerinin iki katı dikkate alınarak yükleme yapılmıştır. Bu yaklaşım, analizin doğruluğunu sağlamak amacıyla kullanılan bir yöntemdir.

Yük uygulama aşamasında iki farklı yaklaşım uygulanmıştır. İlk olarak, deneylerden elde edilen ortalama kuvvet taşıma kapasitesi değerlerinin sandalye modellerine deneylerde uygulanan noktalardan uygulanması yapılmıştır. Bu sayede, sandalyelerin kırılması anında eleman uçlarında oluşan eğilme gerilmeleri elde edilmiş ve Sarıçam malzemenin eğilme emniyet gerilmesi değerleriyle karşılaştırılmıştır. İkinci yaklaşımda ise, tüm sandalye modellerine sabit değerde bir yük (1000 N) uygulanmış ve aynı yük değeri altında tüm sandalye modellerinin eleman uçlarındaki eğilme gerilmelerinin durumları incelenmiştir. Yük uygulaması sonrasında çözüm işlemi yapılmış ve yapısal analiz gerçekleştirilmiştir.

3 Bulgular ve Tartışma

3.1 Sandalye performans test sonuçları

Deney sandalyelerinin önden arkaya doğru devirli yüklemelere karşı verdikleri deformasyon karakteristikleri incelendiğinde, sandalyenin genel sisteminin yük uygulanan noktadan başlayarak önden arkaya doğru bir yer değiştirme (deplasman) gösterdiği görülmüştür. Bunun yanı sıra, ön ayak ile yan kayıt birleşimlerinin üst noktaları ve arka ayak ile yan kayıt birleşimlerinin alt noktaları dönme merkezleri haline gelerek açısal deformasyon (rotasyon) meydana gelmiştir. Benzer deformasyonlar, sandalyelerin ön ayak-alt ara kayıt ve arka ayak-alt ara kayıt birleşimlerinde de gözlemlenmiştir. Bu deformasyon tipi, sandalyenin yük altında nasıl bir yapısal davranış sergilediğini ve özellikle birleşim noktalarının deformasyona duyarlı olduğunu göstermektedir. Sandalyelerin tipik deformasyonları, Şekil 7'de gösterilmiştir.

Şekil 7. Önden arkaya yüklenmiş deney sandalyelerinin tipik deformasyonu

Önden arkaya yapılan performans testlerinde, Şekil 7'de görüldüğü gibi, ön ve arka ayakları bağlayan zıvanalı yan kayıt ve alt ara kayıt birleşimlerinde rotasyona bağlı açılma, kırılma ve kopma gibi deformasyonlar meydana gelmiştir. Tüm testlerde sadece bağlantı noktalarında deformasyonlar gözlenmiş olup sandalye elemanlarının kendisinde herhangi bir kırılma veya benzeri deformasyon oluşmamıştır. Bu durum, çerçeve tipi mobilyalarda en kritik bölgelerin birleşim yerleri olduğunu açıkça göstermektedir. Birleştirme noktalarının yapısal dayanımı, mobilya sisteminin genel performansını ve dayanıklılığını belirlemede önemli bir faktördür.

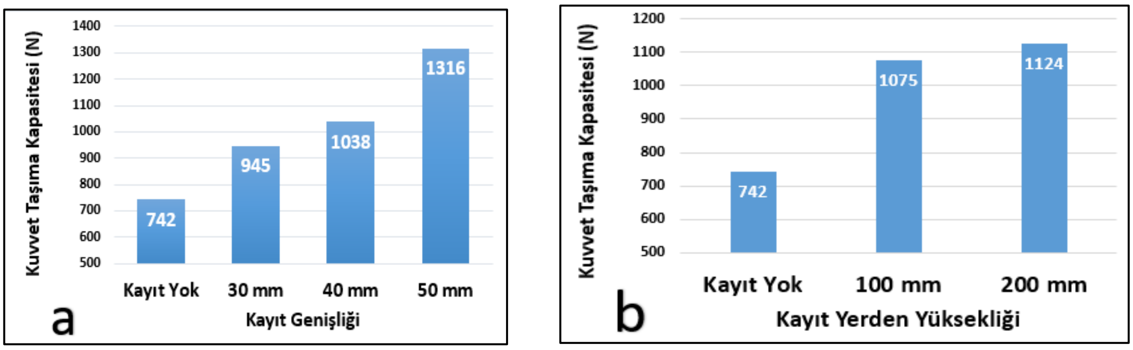
Deney sandalyelerinin devirli basamaklı yükleme metoduyla önden-arkaya yönde gerçekleştirilen performans testleri sonucunda elde edilen kuvvet taşıma kapasitesi değerleri ve toplam devir sayıları varyasyon katsayıları ile birlikte Çizelge 5’ te verilmiştir.

Çizelge 5. Deney sandalyelerinin performans değerlerine ilişkin veriler

Kayıt Yerden Yüksekliği (h) (mm)	Kayıt Genişliği (b) (mm)	N	Kuvvet Taşıma Kapasitesi (N)	Ortalama Performans (N)	v (%)	Toplam Devir Sayısı	Ortalama Devir sayısı	v (%)
Kontrol Sandalyeleri (Kayıtsız)	Kontrol Sandalyeleri (Kayıtsız)	1	779			116263		
		2	779	742	8,64	108558	103521	15,33
		3	668			85743		
Kayıt Yerden Yüksekliği 100 mm	Kayıt Genişliği 30 mm	1	890			142276		
		2	890	927	6,91	138344	147835	8,92
		3	1001			162884		
	Kayıt Genişliği 40 mm	1	1001			159789		
		2	1001	1001	0,00	162884	161365	0,96
		3	1001			161422		
	Kayıt Genişliği 50 mm	1	1334			233130		
		2	1334	1297	4,95	235748	226119	6,40
		3	1223			209480		
Kayıt Yerden Yüksekliği 200 mm	Kayıt Genişliği 30 mm	1	890			143756		
		2	1001	964	6,66	163254	157517	7,60
		3	1001			165542		
	Kayıt Genişliği 40 mm	1	1001			170587		
		2	1112	1075	5,97	185587	182231	5,70
		3	1112			190520		
	Kayıt Genişliği 50 mm	1	1334			241587		
		2	1334	1334	0,00	237473	237510	1,71
		3	1334			233471		

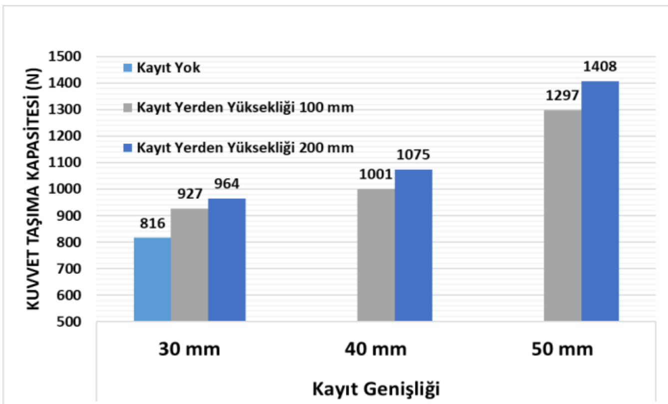
N: Örnek yineleme sayısı, v: Varyasyon katsayısı

Bu aşamada, deney sandalyelerinin ortalama kuvvet taşıma değerleri karşılaştırılmak suretiyle, yan çerçevede kayıt bulunmasının, kayıt var ise kayıt ekseninin yerden yüksekliğinin ve kayıt elemanını kesit ölçülerinin kuvvet taşıma kapasitesi üzerindeki etkileri incelenmiştir (Şekil 8a,b).



Şekil 8. Kayıt genişliği (a) ve yüksekliğine (b) göre ortalama kuvvet kapasitesi değerleri

Buna göre, yan çerçevede kayıt elemanı yer alması ve bu elemanın genişliğinin artmasının kuvvet taşıma kapasitesini önemli derecede artırmıştır. Yan çerçeveye yerden yükseklikten bağımsız olarak, 21 x 30 mm kesit ölçülerinde kayıt elemanı eklenmesi %27; 21 x 40 mm kesit ölçülerinde kayıt elemanı eklenmesi %40; 21 x 50 mm kesit ölçülerinde kayıt elemanı eklenmesi ise %77 oranında kuvvet kapasitesini artırmıştır. Buna göre, sandalye yan çerçevelerinde ara kayıt elemanının kullanılması gerektiği ve 21 x 50 mm kesit ölçülerine sahip olmasının uygun olacağı söylenebilir. Ancak, bu elemanın yerden yüksekliğinin artmasının önden-arkaya kuvvet kapasitesini nispeten az bir miktar arttırdığı görülmüştür. Yan çerçevedeki ara kayıt elemanının, kesit ölçülerinden bağımsız olarak, yerden 100 mm yukarıda olacak şekilde yerleştirilmesi %45, yerden 200 mm yukarıda olacak şekilde yerleştirilmesi ise %52 oranında kuvvet kapasitesini yükseltmiştir. Bununla birlikte, kayıt elemanını yerden yüksekliğinin 100 mm den 200 mm' ye çıkarılması kuvvet taşıma kapasitesini sadece %5 arttırmıştır. Buna göre sandalye yan çerçevelerinde ara kayıt elemanının kullanılması gerektiği bu elemanın ekseninin de yerden 200 mm yukarıda olmasının mukavemet açısından uygun olacağı söylenebilir. Çalışma kapsamında denenen değişkenlerden hem kayıt genişliği hem de kayıt yerden yüksekliği faktörünün etkisinin de dikkate alınarak yapılan karşılaştırma sonuçları Şekil 9' da gösterilmiştir.



Şekil 9. Kayıt genişliği ve kayıt yerden yüksekliğine göre ortalama kuvvet kapasiteleri

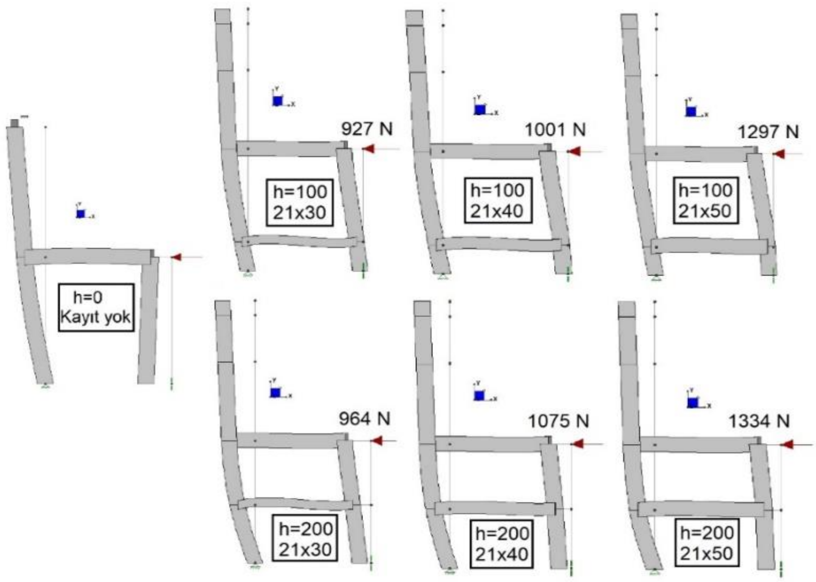
Bu grafik incelendiğinde, sandalye yan çerçevelerinde ara kayıt elemanı kullanılmasının ve bu elemanın kesit ölçülerinin arttırılmasının önemli derecede, yerden yüksekliğinin artırılmasının ise nispeten daha düşük oranda olacak şekilde sandalyenin önden-arkaya yük taşıma kapasitesini artırdığı açıkça görülmektedir.

Deneylerde, sandalyelerin kırıldığı andaki devir sayısı ve son 25000 devri tamamlamış olan yük değeri sandalyenin yaşam ömrü (kuvvet taşıma kapasitesi) olarak kaydedilmiştir. Elde edilen mukavemet değerleri, ALA' da verilen hafif, orta ve ağır kabul edilebilir tasarım yükleri ile karşılaştırılmıştır. ALA' de verilen hafif, orta ve ağır kabul edilebilir servis yükleri sırasıyla 1334,4 N, 1556,8 N ve 1779,2N' dur (ALA, 1982; Eckelman, 1995; Eckelman, 1999). Buna göre, test edilen sandalyelerden sadece yan çerçevesinde yerden yüksekliği 200 mm ve kesit ölçüleri 21 x 50 mm kayıt elemanı bulunan sandalyeler ev içi kullanımlar için uygun bulunmuştur. Denenen diğer sandalyeler ev içi kullanımlar için bile uygun mukavemette olmayıp, mukavemet geliştirici, güçlendirici optimizasyon çalışmalarına ihtiyaç duymaktadır.

3.2 Bilgisayar destekli nümerik analiz sonuçları

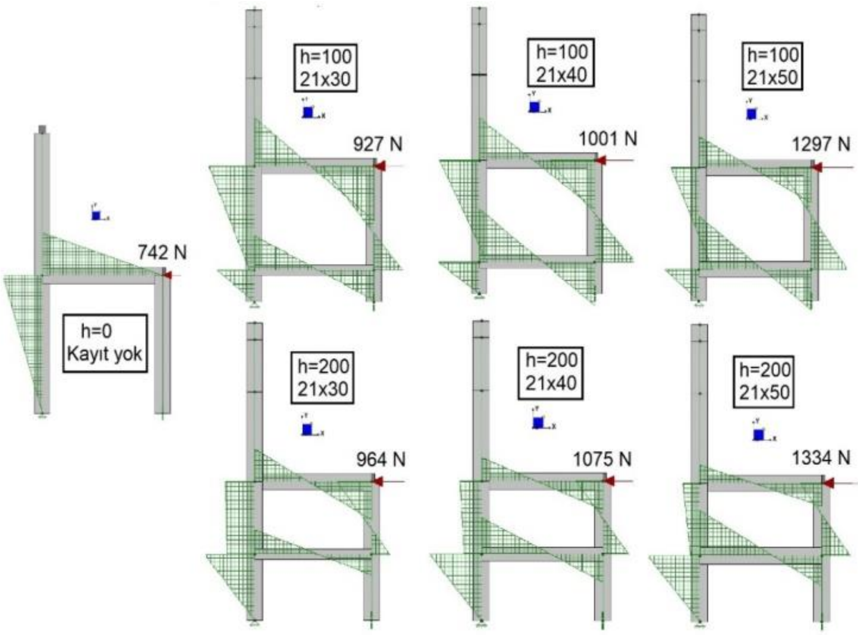
Yapısal analizler, her bir sandalye modeli için, gerçek deneylerde elde edilen ortalama kuvvet taşıma kapasitesi değerlerinin ve ayrıca her bir modele sabit bir yük değerinin (1000 N) yükleme yönü önden-arkaya yönde olacak şekilde uygulanması ile gerçekleştirilmiştir. Yapısal analizler sonucunda her bir sandalye modelinde meydana gelen genel deformasyon karakteristiği Şekil 10' de yan görünüş olarak gösterilmiştir.

Deney sandalyelerinin deformasyon şekli ve deformasyona uğrayan birleşim noktaları incelendiğinde, gerçek testler ile yapılan yapısal analizlerin sonuçlarının tutarlı olduğu görülmüştür. Sandalyelerin performans analizinde, önden arkaya uygulanan yükler sonucunda elemanlarda oluşan moment kuvvetleri ve bunların oluşturduğu eğilme gerilmeleri dikkate alınmıştır. Moment kuvvetlerinin davranışı, eksenel ve kesme kuvvetlerinden farklıdır. Eksenel ve kesme kuvvetleri eleman boyunca her noktada sabit kalırken, moment kuvvetleri elemanın başlangıcından sonuna kadar değişkenlik göstermektedir. Bu durum, elemanların eğilme gerilmeleriyle deformasyona uğramasına neden olmaktadır. Bu şekilde yapılan analizler, sandalyelerin gerçek davranışını ve yapısal dayanıklılığını daha iyi anlamamıza olanak sağlar.



Şekil 10. Modellenen sandalyelerin tipik deformasyon karakteristikleri

Sandalye iskeletini oluşturan tüm elemanlarda oluşan momentler ve buna bağlı olarak meydana gelen eğilme gerilmeleri, üç boyutlu yapısal analizler aracılığıyla elde edilmiştir. Yapısal analizlerin sonuçlarına dayanarak, sandalye elemanlarında oluşan momentlerin dağılımını gösteren moment diyagramları, her bir sandalye modeli için Şekil 11'de sunulmuştur. Bu diyagramlar, sandalye elemanlarının yükler altında nasıl davrandığını ve hangi bölgelerde daha fazla deformasyon meydana geldiğini görsel olarak ortaya koymaktadır. Ayrıca, momentlerin yan çerçeve birleştirmelerine dağılım oranları da Çizelge 6' da verilmiştir



Şekil 11. Modellenen sandalyelerin moment dağılım diyagramları

Çizelge 6. Yan çerçeve birleştirmelerindeki moment dağılımı ve oranları (Nm, %)

Sandalye Modeli	Moment ve Dağılım Oranı (Nm, %)							
	Yan Çerçevedeki Birleştirme							
	Ön Ayak-Yan Kayıt		Arka Ayak-Yan Kayıt		Ön ayak-Ara Kayıt		Arka ayak-Ara Kayıt	
	Moment	Oran	Moment	Oran	Moment	Oran	Moment	Oran
Ara Kayıtsız	0	0	311,64	100	-	-	-	-
h=100 (21 x 30)	125,84	33	113,69	29	69,95	18	79,85	20
h=100 (21 x 40)	108,28	26	96,63	23	96,77	23	118,74	28
h=100 (21 x 50)	119,99	22	107,35	20	135,79	25	181,60	33
h=200 (21 x 30)	131,65	33	115,85	28	70,60	18	86,78	21
h=200 (21 x 40)	110,27	25	93,94	20	104,63	24	142,66	31
h=200 (21 x 50)	108,92	20	91,21	16	140,82	26	219,34	38

Momentler ve dağılım oranları incelendiğinde, ara kayıtsız bir sandalyede, "arka ayak-yan kayıt" birleştirmesinin yan çerçevede kuvvetin yerden yüksekliğine göre oluşan toplam momentin tamamını taşıdığı ve kritik bir birleştirme haline geldiği görülmektedir. Diğer sandalye modellerinde ise momentlerin yan çerçevedeki birleştirmelere dağıldığı görülmektedir. Buna göre, sandalye yan çerçevesinde, kesit ölçüsü ve yerden yüksekliği ne olursa olsun, ara kayıt elemanı bulunmasının mukavemeti olumlu etkilediği söylenebilir. Bu aşamadan sonra, deneyl kuvvetleri altında en büyük eğilme gerilmesinin oluştuğu elemanlar yapı analizi sonuçlarından tespit edilerek, bu kritik elemanlarda oluşan eğilme gerilmesi değerleri, sandalyelerin üretiminde kullanılan malzemeler için deneyler sonucunda belirlenmiş olan eğilme emniyet gerilmesi değerleri ile Çizelge 7' de karşılaştırılmıştır.

Çizelge 7. Kritik elemanlarında eğilme gerilmeleri ile emniyet gerilmelerinin karşılaştırılması

Sandalye Modeli	Kritik Eğilme Elemanı	Deney Eğilme Gerilmesi (N/mm^2)	Emniyet Gerilmesi (N/mm^2)	Sonuç
Ara Kayıtsız	Yan Kayıt (M2i, M6i)	35,62	33	Başarısız
h=100 (21 x 30)	Ara Kayıt (M4i, M8i)	25,29	33	Başarılı
h=100 (21 x 40)	Ara Kayıt (M4i, M8i)	21,19	33	Başarılı
h=100 (21 x 50)	Ara Kayıt (M4i, M8i)	20,74	33	Başarılı
h=200 (21 x 30)	Ara Kayıt (M4i, M8i)	27,37	33	Başarılı
h=200 (21 x 40)	Ara Kayıt (M4i, M8i)	25,38	33	Başarılı
h=200 (21 x 50)	Ara Kayıt (M4i, M8i)	30,49	33	Başarılı

Eğilme gerilmeleri yapı analizi programından alınmış olup, hesaplamalarda "$\sigma_e=Mc/I_z$" fomülü kullanılmaktadır. Burada, *c* (*mm*); elemanın yükün uygulandığı yöndeki ağırlık merkezinden kenarına olan en büyük mesafe (*h/2*), I_z (mm^4); ise ilgili yöndeki eylemsizlik momentini ifade etmektedir. Emniyet gerilmesi, sandalye çerçevelerinin dayanma sınırını belirleyen bir parametre olarak, eğilme direnci deneylerinden elde edilen maksimum değerin üçte biri (33 N/mm^2) olarak belirlenmiştir (Eckelman, 2003). Ara kayıtsız sandalyelerde en yüksek eğilme gerilmeleri "yan kayıt" elemanlarında, ara kayıtlı sandalyelerde ise "ara kayıt" elemanlarında gözlemlenmiştir. Deney sonuçlarına göre, ara kayıtlı sandalyelerin kritik elemanlarında oluşan eğilme gerilmeleri, eğilme emniyet gerilmesi değerlerinin altında kalmış ve bu momentleri başarılı bir şekilde karşılanmıştır. Bu durum, sandalyelerin elemanlarında deformasyon oluşmadığını, ancak birleştirme noktalarında deformasyonların meydana geldiğini göstermektedir. Gerçek deneylerde de deformasyonların birleştirmelerde olduğu gözlemlenmiştir. Sonuç olarak, kayıt genişliğinin artmasıyla eleman uçlarında gerilmelerin azaldığı ve birleştirmelerin daha güvenli hale geldiği sonucuna varılmıştır.

Yapısal analizlerde, ikinci yaklaşım olarak, her bir sandalye modeline sabit (1000 N) bir yük uygulanmış ve her bir model sandalyenin "yan kayıt" ve "alt ara kayıt" elemanlarının uçlarında oluşan eğilme gerilmesi değerleri elde edilmiş ve eleman uçlarında oluşan bu eğilme gerilmeleri karşılık gelen birleştirmelere göre değerlendirilmiştir (Çizelge 8).

Çizelge 8. Yan çerçeve birleştirmelerine karşılık gelen eğilme gerilmeleri

Sandalye Modeli	Eğilme gerilmesi (N/mm^2) Yan Çerçevedeki Birleştirme			
	Ön Ayak-Yan Kayıt	Arka Ayak Yan Kayıt	Ön ayak-Alt Ara Kayıt	Arka ayak-Alt ara Kayıt
Ara Kayıtsız	0	48	-	-
h=100 (21 x 30)	15,60	13,93	24,05	27,29
h=100 (21 x 40)	12,39	10,91	17,41	21,19
h=100 (21 x 50)	10,58	9,34	12,09	15,99
h=200 (21 x 30)	15,85	13,47	23,49	28,40
h=200 (21 x 40)	11,87	9,67	17,74	23,61
h=200 (21 x 50)	9,42	7,48	12,40	18,70

Birleştirmelerdeki eğilme gerilmesi değerleri incelendiğinde, ara kayıt elemanının kesit ölçülerinin artmasının birleştirmelere karşılık gelen eğilme gerilmelerini önemli oranda azalttığı ve bu sayede birleştirmelerin daha güvenli hale geldiği söylenebilir. Bununla birlikte, ara kayıt elemanının yerden yüksekliğinin 100 mm' den 200 mm'ye çıkarılmasının ise birleştirmelere karşılık gelen eğilme gerilmelerinde çok küçük oranlarda düşüş sağladığı görülmüştür. Nümerik analizlerden elde edilen bu sonuçların, gerçek deneylerden elde edilen deformasyon karakteristikleri ile tutarlı olduğu görülmüştür.

4 Sonuçlar ve Öneriler

Çalışmanın sonucunda elde edilen sonuçlar aşağıda maddeler halinde verilmiştir:

- Sandalye yan çerçevelerinde ara kayıt elemanının varlığı ile sandalyenin kuvvet taşıma kapasitesinin önemli derecede arttığı görülmüştür.
- Sandalye yan çerçevelerinde kullanılacak ara kayıt elemanının yerden yüksekliğinin 100 mm'den 200 mm'ye artırılması kuvvet kapasitesiinde önemli bir artışa neden olmamıştır.
- Sandalye yan çerçevelerinde kullanılacak ara kayıt elemanının genişliğinin artırılması önden-arkaya kuvvet taşıma kapasitesini önemli derecede artırmıştır.
- Nümerik analizlerden elde edilen sonuçlar, gerçek deneylerden elde edilen deformasyon karakteristikleri hakkında makul tahminler vermiştir.

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Experimental analysis of the bending behaviour of woods with kerf-cutting technique

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ABSTRACT: Wood has been recognised for its ecological benefits and lightness throughout history. Its flexibility can be significantly enhanced when processed with proper techniques, inspiring various architectural products and furniture. This study aims to investigate the bending capacity of different natural wood samples made flexible using the kerf-cutting technique and the maximum load they can bear at their maximum bending capacity. Although there are studies on how kerf-cutting techniques can increase the flexibility of various wood products, the relationship between the bending capacity provided by the kerf technique and load-bearing capacity has not been examined, making this study original. The paper first examines the general physical properties and bending capacities of different wood types. Then, a two-stage experimental study is presented. The first step discusses the effects of different kerf-cutting techniques on wood flexibility. The bending and load-bearing capacities of three different types of wood are investigated in the second step. Results indicate that ash has the highest flexibility, while walnut demonstrates greater load-bearing strength than ash, making it suitable for designs requiring higher strength.

Keywords: Wood, kerf-cutting technique, bending, load-bearing capacity

Kerf-kesme tekniği uygulanmış ahşapların eğilme davranışının deneysel analizi

ÖZ: Ahşap, tarih boyunca ekolojik faydaları ve hafifliği ile tanınmıştır. Doğru tekniklerle işlendiğinde esnekliği önemli ölçüde artırılabilir, çeşitli mimari ürünlere ve mobilyalara ilham kaynağı olabilir. Bu çalışmanın amacı, kerf kesim tekniği ile esneklik kazandırılmış farklı doğal ahşap numunelerinin esneklik düzeylerini ve bu düzeylerde taşıyabildikleri azami yükü incelemektir. Kerf kesme tekniklerinin çeşitli ahşap ürünlerin esnekliğini nasıl artırabileceğine dair çalışmalar olmasına rağmen, bu tekniğin sağladığı eğilme kapasitesi ile yük taşıma kapasitesi arasındaki ilişki incelenmemiş olması bu çalışmayı özgün kılmaktadır. Makalede öncelikle farklı ağaç türlerinin genel fiziksel özellikleri ve eğilme kapasiteleri incelenmiştir. Sonrasında ise iki etaplı bir deneysel çalışma ortaya konmuştur. Bu deneysel çalışmanın ilk aşamasında, farklı kerf kesim tekniklerinin ahşabın esnekliğine etkisi, ikinci aşamada ise üç farklı ahşap tipinin esneklik ve taşıma kapasiteleri araştırılmıştır. Sonuçlara göre, dişbudağın en fazla esnekliğe sahip olduğu, cevizin ise yük taşıma kapasitesi olarak dişbudaktan daha yüksek mukavemet gösterdiği, dolayısıyla daha fazla mukavemet gerektiren tasarımlar için uygun olduğu belirlenmiştir.

Anahtar kelimeler: Ahşap, kerf kesim tekniği, eğilme, yük taşıma kapasitesi

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1 Introduction

Wood is one of the most common materials in the architecture and construction industry due to its versatility and availability. It can be utilised in various applications with minimal processing, such as cutting and drying. Furthermore, its unique fibrous composition allows the wood to bend naturally, creating curved and flexible elements. This natural ability to bend can be further enhanced through techniques such as kerf-cutting (Capone & Lanzara, 2019), steam bending (Whinney, 2019), lamination bending (Bianconi & Filippucci, 2020), cold bending (Hao & Chen, 2024), chemical bending (Mao et al., 2024), soaking in water (Shi et al., 2024), heat bending (Kwon et al., 2024), mechanical bending (Florkowsk et al., 2024), microwave heating (Zhang et al., 2020) and vacuum press bending (Lee et al., 2021).

The production of flexible and curved surfaces has become a prominent area of research in architecture, with many studies focusing on materials and fabrication techniques to achieve curvilinear geometries and freeform surfaces. Among these techniques, kerf-cutting is a subtractive manufacturing method that transforms rigid, planar materials into curved surfaces. It is widely used across various industries, from crafting furniture and decorative structures to producing musical instruments. In architecture and interior design, kerfing is employed not only to create flexible surfaces (Shadid et al., 2022) but also to develop technical components such as façade panels (Teuffel et al., 2009) and acoustic panels (Greenberg & Körner, 2014). For example, complex kerfed surfaces are incorporated into façade designs to mitigate the adverse effects of strong winds (Teuffel et al., 2009), while they are used for acoustic optimisation in interior spaces (Greenberg & Körner, 2014).

Kerf bending involves machining a panel into a specific cutting pattern to design flexible and free-form systems (Zarrinmehr, 2017). Depending on the chosen pattern, a rigid panel can acquire bending capacity in one direction while retaining its strength in the other, thanks to the gaps introduced by the cuts (Capone & Lanzara, 2019). Three primary types of kerf-cutting are single-sided, double-sided, and cuts that penetrate entirely through the panel. Each type produces varying levels of bending capacity, offering a range of possibilities for design and structural performance (See Figure 1).

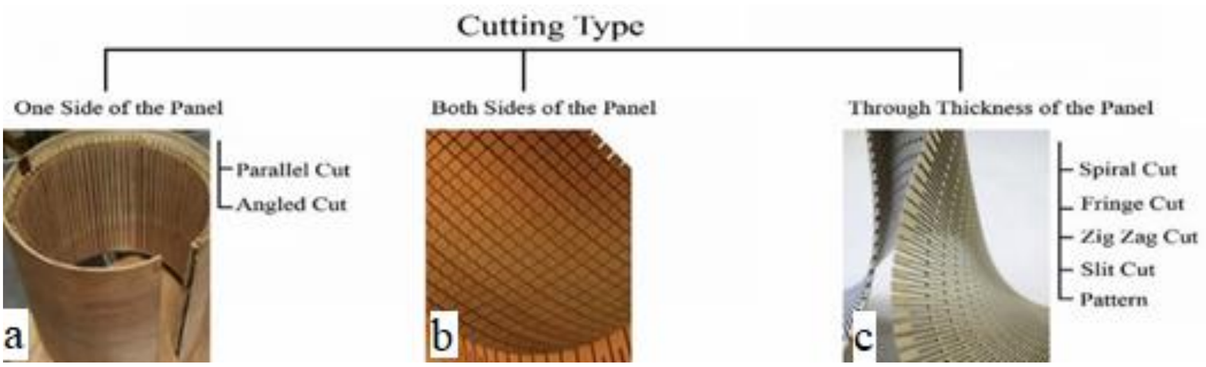

Figure 1. Kerf technical methods (Bianconi & Filippucci, 2020)

The first cutting type is the traditional approach wherein the kerf cut is made on just one side of the panel and examined in two groups: Parallel cutting is when notches are cut parallel to the edges of the panel (see Figure 2a as an example) and Angled Cutting in which notches are made at an angle to the edges of the panel.

The second type involves cutting both sides of the panel following a specific set of rules (see Figure 2b as an example). This process allows for the creation of double-curvature surfaces. The parametric design of the cuts ensures precision in achieving the desired curves (Capone & Lanzara, 2019).

The third type is an advanced technique based on "cutting where needed." In this method, cuts are made crosswise on both sides of the panel using an improved kerf technique. This allows the wood panel to be bent into 3D shapes, creating a double-curvature surface. The blanks must be processed meticulously for the curves to be smooth (Bianconi & Filippucci, 2020) (See Figure 2c as an example).

Many studies in the literature deal with the relationship between kerf-cutting techniques and the form flexibility provided by the kerf technique, as summarised in Kırkpınar et al. (2024). However, no study investigates the relationship between the type of wood, the kerf-cutting technique, and the load-bearing capability of the sample. This study aims to fill this gap in the literature. Experiments were conducted to assess the bending capacity of various wood types and the loads they could endure to achieve this aim. Based on the test results, a comprehensive analysis of the flexural capacity was performed, and valuable information was provided to the literature. The method involved testing samples of materials in a workshop setting. Simple timber beams were subjected to a single-centred load to determine their deformation. The bending radius and the load-bearing capacity at rupture were precisely measured for different kerf patterns and wood types. Finally, the data from these experiments were analysed and optimised through comparative analysis to enhance the performance of flexible prototypes.

1.1 Main Concepts

Wood is widely used in various fields, ranging from solid wood to engineered wood products such as plywood, fibreboard, particleboard, laminated timber, and carpenter board (Kretschmann, 2010). Additionally, it serves as a coating material and functions as a structural element or complement in architectural constructions. The effective use of wood, particularly in bending applications, depends on selecting appropriate wood species and varieties based on their mechanical properties (Doğu, 2016). In this context, wood species are classified according to specific gravity, compressive strength, bending strength, and modulus of elasticity. Since physical characteristics influence the mechanical properties of wood, this classification is presented in two tables for hardwoods and softwoods (See Tables 1 and 2).

Hardwoods, classified as angiosperms with anatomically porous structures, are distinguished by their broad leaves. They are widely used in construction, architecture, and interior woodworking. Common broad-leaved tree species with similar anatomical characteristics include maple, chestnut, alder, birch, hornbeam, beech, ash, walnut, plane, poplar, oak, willow, elm, olive, and ebony (Farmer, 1972). Most tropical trees, particularly teak and iroko, are also classified as hardwoods (Kukachka, 1970) (see Table 1).

Softwoods, botanically classified as gymnosperms and conifers, are characterised by their non-porous anatomical structure. They typically have needle- or scale-like leaves that remain evergreen. Softwoods are widely used in construction for various applications, including scaffolding, cabinetry, framing, veneering, flooring, and panelling. Notable coniferous species include fir, cedar, cypress, juniper, spruce, pine, larch, linden, mahogany, and ayous (Alden, 1997) (see Table 2).

Table 1. Properties of Hardwoods (reproduced from Timberpolis, 2003)

Type	Origin	Body/ Diameter	Tree Size / Height	Specific Weight	Bending Strength	Modulus of Elasticity	Compressive Strength	Use Area
Maple	North America	0,6 - 1,0 m	25 - 30 m	0.44	73,8 MPa	10,00 GPa	41,0 MPa	Solid and veneered furniture, musical instruments, kitchen appliances, shoe molds, carving, marquetry, finishing works, parquet, toys, plywood, tool handles,
Cherry	North America	1,0 - 1,5 m	15 - 30 m	0.59	84,8 MPa	10,30 GPa	49,0 MPa	window frames, exterior cladding, parquet, pergola, furniture
Mulberry	China	0,3 – 0,5 m	10 - 15 m	0.69	80,6 MPa	9,32 GPa	48,2 MPa	solid and veneered furniture, turning, plywood tool
Chestnut	Europe, Asia	1,5 - 2,0 m	30 - 37 m	0.44	71,4 MPa	8,61 GPa	43,8 MPa	window frames, exterior cladding, parquet, pergola, furniture
Alder	Europe, Asia, North America	0,6 - 1,0 m	15 - 24 m	0.58	71,7 MPa	8,48 GPa	47,4 MPa	Solid wood, plywood, veneer, modelling, clogs, toys, cigarette boxes, carved and turned works
Birch	North America	0,6 - 1,0 m	20 - 30 m	0.55	114,5 MPa	13,86 GPa	56,3 MPa	furniture, carved works, musical instruments, sled and ski, plywood production, barrel, reel, shuttle, shoe mold
Hornbeam	Europe, Asia	0,6 - 1,0 m	15 - 20 m	0.598	110,4 MPa	12,10 GPa	50,5 MPa	small-sized products, kitchen appliances, shoe mold, measurement tools
Beech	United Nations, North America, Europe	1 - 1,5 m	30 - 40 m	0.55	110,1 MPa	14,31 GPa	57,0 MPa	furniture, plywood, cars, parquet, shoe molds, packing crates, toys, boat and oven shovels, tool handles,
Ash	North America	0,6 - 1,5 m	20 - 30 m	0.54	103,5 MPa	12,00 GPa	51,1 MPa	solid and veneered furniture, turning, plywood tool making, sports tools
Walnut	United Nations	1 m	30 m	0.36	55,9 MPa	8,14 GPa	35,2 MPa	furniture, solid and veneered, carved and turned works, musical instruments
Plane	Europe	1 - 1,5 m	20 - 35 m	0.52	74,7 MPa	8,90 GPa	40,8 MPa	kitchenware making, packaging industry turned and inlaid works
Popular	North America	1 - 1,5 m	25 - 30 m	0.31	46,9 MPa	7,59 GPa	27,7 MPa	match production veneer and plywood
Oak	Turkey, Europe	1,2 - 2,0 m	25 - 37 m	0.62	114,3 MPa	10,81 GPa	56,4 MPa	doors, windows, stairs, flooring, parquet, barrel, wagon, car, ship, boat, bridge, and pier, furniture
Willow	Europe, Asia	1 - 1,2 m	20 - 30 m	0.34	56,2 MPa	7,76 GPa	26,9 MPa	cosmetics, medical
Elm	Europe	1 - 1,5 m	25 - 35 m	0.43	68,7 MPa	7,52 GPa	32,0 MPa	furniture, solid and veneer, turning, parquet, boating, bridge, and pier
Olive	Mediterranean, Europe, Asia and Africa	0,3	8 - 15 m	0.94	64.39 MPa	4,44 GPa	53.17 MPa	coating in furniture production, brush handle, trinket making
Teak	Asia	1 - 1,5 m	30 - 40 m	0.55	96,1 MPa	10,83 GPa	53,6 MPa	yachts, garden furniture
Iroko	Africa	1 - 1,5 m	30 - 40 m	0.55	87,6 MPa	9,38 GPa	54,0 MPa	indoor and outdoor furniture, flooring, exterior, stairs
Ebony	Africa	0,6 m	15 - 18 m	0.90	167,6 MPa	17,20 GPa	89,5 MPa	valuable and expensive furniture, turned, inlaid, and carved works, musical instruments, furniture, door handles, and knife handles

Table 2. Properties of Softwoods (reproduced from Timberpolis, 2003)

Type	Origin	Body/ Diameter	Tree Size / Height	Specific Weight	Bending Strength	Modulus of Elasticity	Compressive Strength	Use Area
Fir	Germany, France, Asia	1 - 1,5 m	30-46 m	0.353	66,1 MPa	8,28 GPa	41,0 MPa	paper factories, mold, medical, wool dyeing with shells
Cedar	Israel, Lebanon, Turkey	1,5 - 2,1 m	30-40 m	0.41	82,0 MPa	10,10 GPa	42,0 MPa	flooring, panelling, wooden camellia, and pergola
Cypress	North America	1,2 - 1,8 m	30 - 37 m	0.42	76,6 MPa	9,79 GPa	43,5 MPa	Interior and exterior parts of buildings, ships, bridges, and piers, furniture, turned works,
Juniper	North America	1 - 1,2 m	30 - 35 m	0.44	60,7 MPa	6,07 GPa	41,5 MPa	pencil, lumber
Spruce	Europe	1 - 1,5 m	35 - 55 m	0.38	63,0 MPa	9,70 GPa	35,5 MPa	lumber, furniture, paper factories
Pine	United Nations	0,6 - 1 m	18 - 30 m	0.54	112,4 MPa	13,70 GPa	56,1 MPa	medicinal, perfume essence, timber, pulp
Larch	Europe, Africa, Asia	0,6 - 1 m	20 - 35 m	0.41	64,4 MPa	10,81 GPa	38,4 MPa	construction work, carpentry, various household items, packing cases, bridge, and ship
Linden	Europe	1,5 - 2 m	20 - 40 m	0.42	85,4 MPa	11,71 GPa	44,8 MPa	match production, shoe molds, duralite production, carving arts
Mahogany	Africa	0,7 - 1,2 m	30 - 50 m	0.65	103,0 MPa	9,40 GPa	53,2 MPa	in shipping, musical instruments, frames, parquet, stair making, lathe, carved and inlaid works, solid and veneered furniture
Ayous	Africa	0,7-1.5 m	30 - 50 m	0.38	110,0 MPa	.	30,87 MPa	sauna, sauna accessories, and furniture

A detailed analysis of the hardwood and softwood properties reveals that species such as birch (13.86 GPa), hornbeam (12.10 GPa), beech (14.31 GPa), ash (12.00 GPa), oak (10.81 GPa), teak (10.83 GPa), and ebony (17.20 GPa) among hardwoods, as well as cedar (10.10 GPa), pine (13.70 GPa), larch (10.81 GPa), and linden (11.71 GPa) among softwoods, exhibit relatively high modulus of elasticity. Furthermore, findings by As and Büyüksarı (2010) indicate that certain species, such as alder, beech, birch, fir, hornbeam, spruce, and teak, demonstrate high minimum bending radii both with and without support, making them particularly suitable for bending applications. These insights guided the selection and testing of species in our study, focusing on those with promising mechanical properties for kerf-cutting and bending performance.

1.2 Preliminary experiments

To evaluate the potential of different wood types and kerf patterns for bending applications, several wood species (mulberry, linden, cherry, walnut, chestnut, mahogany, and oak) were cut using two distinct patterns: slit kerf cutting and fringe kerf cutting. The experimental results (Tables 3 and 4) indicate that cherry, walnut, and chestnut exhibited higher flexibility, whereas mahogany proved challenging to bend. Oak samples experienced breaks and cracks during cutting and could not be tested as a result (Kırkpınar, 2024).

Table 3. Classification of Wood Species' Flexibility

Flexibility Based on the Kerf Technique Depending on Wood Species		
	Mulberry	Linden
Wood Type		
	Slit kerf	Slit kerf
Cutting Type		
	Result	Result
Flexibility		

Table 4. Classification of Wood Species Flexibility

Flexibility Based on the Kerf Technique Depending on Wood Species					
	Cherry	Walnut	Chestnut	Mahagony	Oak
Wood Type					
	Fringe kerf	Fringe kerf	Fringe kerf	Fringe kerf	Fringe kerf
Cutting Type					
	Flexible	Flexible	Flexible	Flexible	Less flexible
Flexibility					

2 Materials and Methods

This study investigated the flexibility achieved through kerf-cutting across various tree species, focusing on the extent of flexibility attainable with this technique as the primary research objective. A detailed evaluation assessed the flexibility of different tree species subjected to kerf cutting. The initial analyses were preliminary and aimed at preparing the experimental setup.

2.1 Materials

After analysing the literature and the preliminary experiments, five different hardwood types (walnut, ash, iroko, cherry, and chestnut) with different bending strengths and modulus of elasticity were chosen among species broadly available for developing industrial products. Due to the unavailability of cherry and chestnut samples with equivalent quality and dryness levels, they were excluded from the testing phase despite promising results in the preliminary experiments. The details of the three selected species (walnut, ash, and iroko) are shown in Figure 2. Walnut was selected for its flexibility as demonstrated in the preliminary tests, while ash wood was chosen based on literature findings indicating its common use in prototyping furniture made with kerf techniques. Iroko was selected for its aesthetic properties and durability. All selected woods were commercially sourced from furniture production suppliers and dried to a moisture content below 17%.

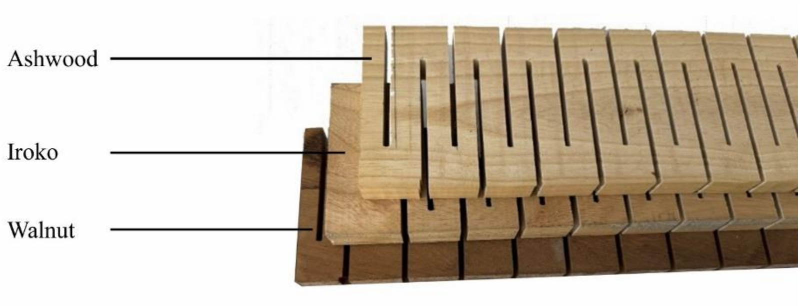

Figure 2. Wood samples used in the test

2.2 Samples' preparation

The selected materials were prepared and cut to fit experimental conditions and testing devices. The test samples were prepared with a length of 500 mm in accordance with the standard seat width in furniture design. They had a width of 80 mm suitable for the saw blade used in cutting and testing, and a thickness of 20 mm consistent with typical material thickness in furniture production (see Figure 3).

Fringe kerf, which is one of the most commonly used cutting methods, was selected for testing due to its relatively simple cutting process compared to other kerf types, referring to the table on kerf-cutting techniques and corresponding examples examined in Kırkpınar et al. (2024). Preliminary experiments determined the optimal kerf spacing: 4 cm intervals were insufficient for elasticity distribution, while intervals less than 2 cm compromised cutting quality and caused breaks due to blade thickness. Consequently, the kerf interval was set to 2 cm. Samples made with 2 cm intervals were called Wa2 (walnut wood), As2 (ash wood), and Ir2 (iroko wood). Three beams were cut for each type of wood.

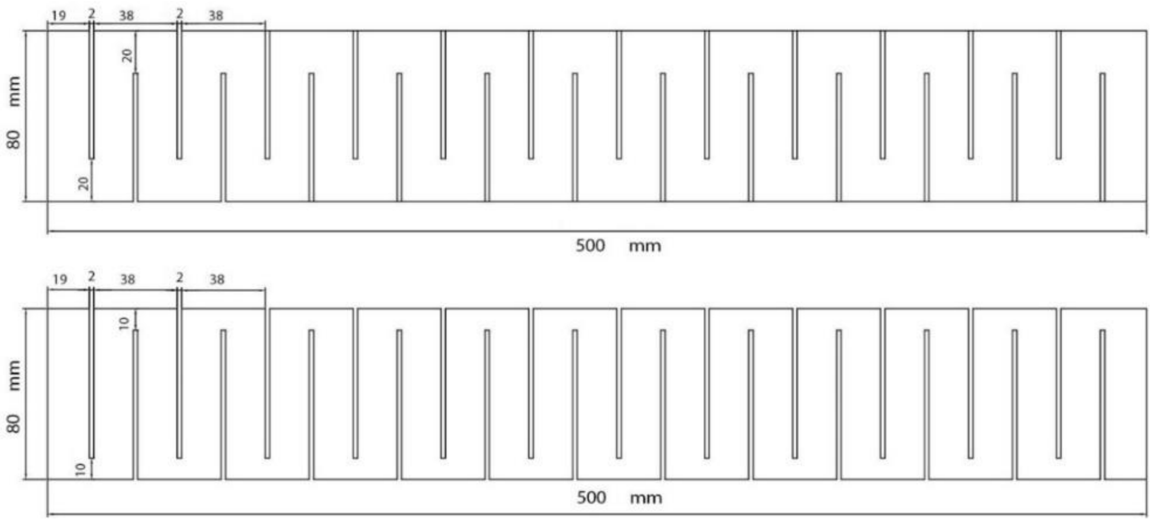

Figure 3. Dimension of the Samples

1 cm kerf depth samples of ash wood were also prepared, owing to the wood's higher bending strength, to understand the impact of the cutting intervals (Timberpolis, 2003). Samples with a 1 cm kerf depth are called As1 (Table 5).

Table 5. Classification of Samples

Sample name	Wood type	Kerf depth	Number of samples
Walnut2 (Wa2)	walnut	2 cm	3
Ash 1 (As1)	ash	1 cm	3
Ash 2 (As2)	ash	2 cm	3
Iroko 2 (Ir2)	iroko	2 cm	3

2.3 Experimental Method

This section presents the methodology used to determine the bending properties of the selected wood species. The methodology aims to identify the maximum deformation at failure and the minimum bending radius of the selected samples. Determining the load at failure and the corresponding maximum deformation is crucial, as it indicates the maximum load the samples can bear. Additionally, the minimum bending radius provides insight into the material's flexibility.

A simple experimental testing method was used to determine the bending properties of wooden beams. A wood beam was placed on two supports spaced 460 mm apart and loosely fixed with nails to allow rotation without sliding, as seen in Figure 4.

The beam was loaded first with 7900 grams and then by increments of 100 grams until it ruptured. The maximum bending radius was determined at rupture. The experiment was repeated on three identical samples for each wood type.

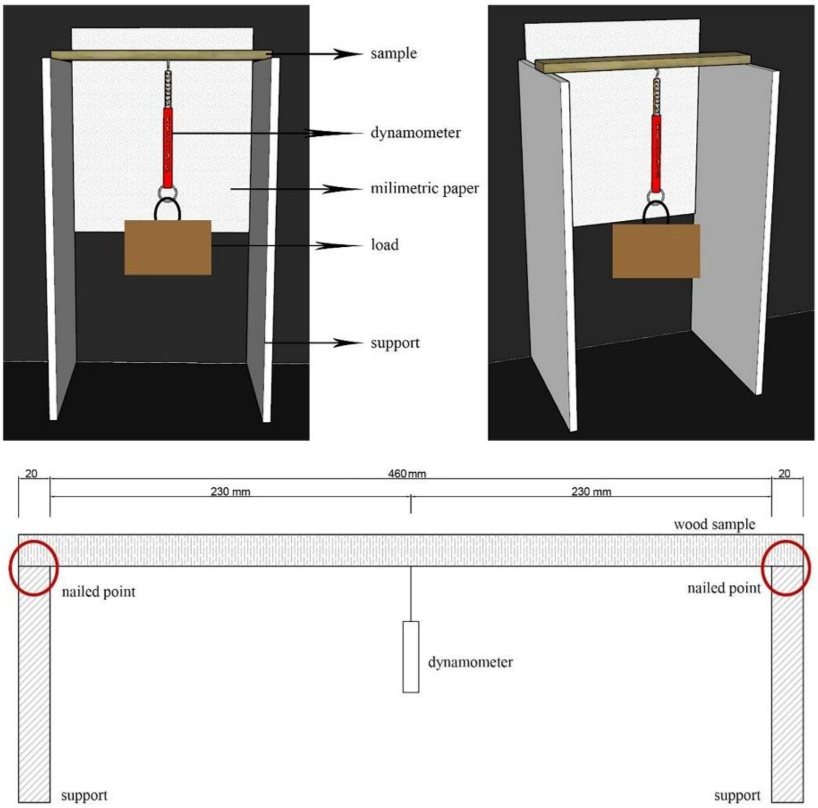

Figure 4. Testing Setup

Simple devices were used to collect relevant data to determine the bending radius and maximum load at rupture.

- A dynamometer was used to determine the load applied to the beam, as all loads were suspended. The maximum load supported at the centre point of the sample when the fracture occurred was recorded by reading it from the dynamometer.
- A millimetric paper was placed behind the setup to measure the deformation of the beam at each step of the experiment, and a high-definition video camera placed perpendicularly in front of the setup was used to record the results.
- Using the camera allowed the exact bending radius at the first visible rupture to be determined. The visible rupture was determined by hearing a cracking sound from the beam.

3 Findings and Discussion

This study sequentially tested nine samples from three different wood types under the same experimental setup in a workshop environment. Three samples of each material were recorded for deformation under a constant load (7900 grams) and deformation at failure. The maximum bending was calculated from the deformation at failure. The results are summarised in Tables 6 and 7 and Figure 5. The deformation for ash wood (As2, 75 mm) and walnut wood (Wa2, 66 mm) under the same load shows that ash wood allows for much more deformation than walnut, which has a smaller resistance to bending. Moreover, no results could be obtained for iroko wood (Ir2) as 7900 grams was above the material's limit.

The failure load and deformation of samples are consistent with the behaviour under a 7900-gram load. Ir2 failed with the smallest load (6200 grams and 71 mm deformation), while As2 failed with a 15400-gram load and 112 mm deformation. Wa2 failed under an 8050-gram load (higher than Ir2) but presented only 70 mm of deformation (less than Ir2).

These results show the impact of the kerf cutting on the deformation and resistance of samples. While ash wood has the highest modulus of elasticity among the three chosen wood types (ref above) and should present a higher rigidity for the same load, As2 samples present more deformation than Wa2 under the same load. Similarly, iroko has higher bending strength and modulus of elasticity than walnut, but Ir2 samples were broken under a smaller load and larger deformation than Wa2 samples (Table 7). This data shows that walnuts seem to have better resistance to deformation, while kerf cuts are better than other wood types despite a lower modulus of elasticity and bending strength. The failure patterns of As2 and Wa2 corroborate this behaviour. Figure 6 shows the failure patterns of As2 and Wa2. As expected, the As2 samples break in the middle at the load's application point. In contrast, Wa2 samples break at the support interface, showing that the failure is due to the weakened connection point obtained by nailing the samples to the support.

In contrast, ash wood allows large deformation before breaking (112 mm and 85 mm, respectively, for As2 and As1) while supporting higher loads than other samples. These results are consistent with ash wood's higher bending strength and modulus of elasticity compared to walnut and iroko wood (Timberpolis, 2003).

The comparison between As1 and As2 samples shows the impact of the cutting intervals on the samples' bending strength. Despite As1 samples having higher flexibility due to the smaller interval between cuts according to the literature, their bending strength and deformation at failure are much lower than those of the As2 samples. However, their breaking patterns are similar to a failure of the timber in the middle of the sample, where the width of the wood is the smallest (see Figure 6). This fact is probably due to the lower amount of material left to support the load, and the only 1 cm width of timber between the cut and the side of the beam, leading to an early failure despite lower deformation.

Table 6. Deformation of samples under a 7900-gram load

sample	Deformation under 7900-gram load Average deformation (mm)	Minimum deformation (mm)	Maximum deformation (mm)
Ir2	Failed	Failed	Failed
Wa2	66	63	68
As2	75	72	79

Table 7. Deformation, maximum load, and bending radius at failure

sample	Deformation and load at failure Average deformation (mm)	Average load (g)	Maximum bending radius (mm) (average radius at failure)
Ir2	71	6200	408
Wa2	70	8050	413
As2	112	15400	292
As1	85	8700	354

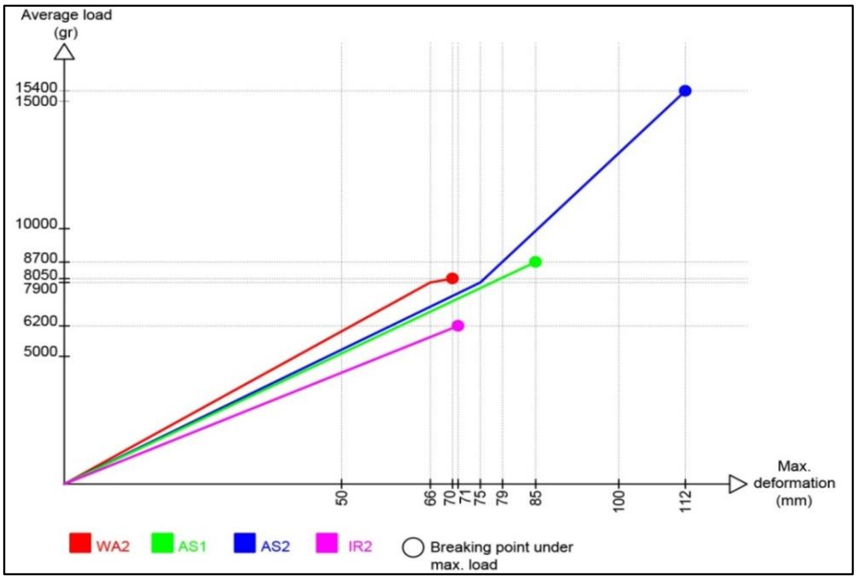

Figure 5. The relationship between average loads and maximum deformation for each sample

It should be noted that the scale of the samples tested influences their load-deformation behaviour. Larger components may experience greater internal stress variations, and the effects of kerf spacing and depth may become nonlinear at increased dimensions. While this study uses a standardised sample size suitable for furniture components, future research should address scalability and its effects on kerf-induced flexibility and strength.

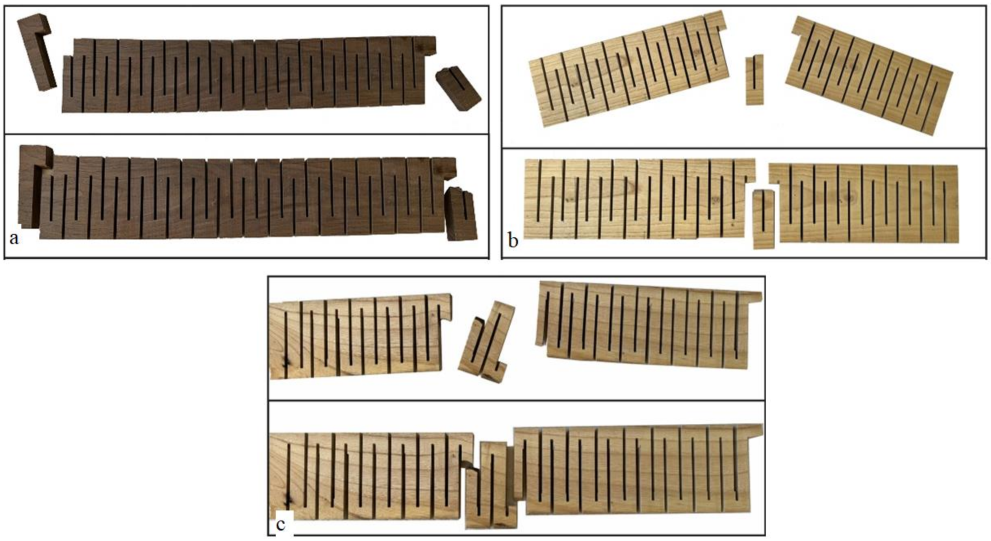

Figure 6. Failure pattern of samples Wa2 (a), As2 (b) and AS1 (c)

4 Conclusion

The literature review reveals limited research on wood processing using the kerf-cutting technique. While this method has been explored in various applications, comprehensive studies on its effects on elasticity and structural performance are scarce. To address this gap, an experimental setup was designed to evaluate the bending capacity of wooden pieces processed using the kerf technique.

- The results of the experiments indicate that iroko is not well-suited for kerf cutting as the process significantly reduces its strength and allows only minimal deformation. Among the three wood species tested for wooden furniture prototypes, ash exhibited the highest deformation and bending strength, making it the most flexible option. Walnut, on the other hand, demonstrated lower deformation under load compared to ash. Due to its reduced flexibility, walnut is preferable for designs that require greater stiffness and higher structural strength.
- The findings also emphasise the importance of testing different kerf patterns to determine the most suitable design for specific applications. The kerf-cutting technique considerably reduces the material's strength under load, making it essential to select an appropriate pattern to achieve the desired balance between flexibility and structural integrity.
- Based on the deformation and stress results, walnut appears suitable for semi-structural elements where strength is critical. In contrast, with higher deformation before failure, ash could be advantageous for kinetic elements such as acoustic panels, flexible screens, or ergonomic furniture components requiring adaptable curvature.
- The kerf-cutting technique remains underrepresented in existing research despite its potential. Further studies are needed to identify the most suitable wood species for kerf applications and assess the impact of kerf patterns on both strength and bending performance. Additionally, although visual observations suggest that the technique may be effective for kinetic panel applications, the long-term impact of repeated loading and unloading cycles has not been examined. A comparative study of different timber species under cyclic loading conditions would provide valuable insights for optimising the use of kerf-cut wood in structural and design applications.

Authors' Contribution

Gökçe Kırkpınar: Conceptualisation (development of research idea and aims), conducting research, conducting analyses, resources, visualization, drafting an article, writing an article **Yenal Akgün:** Conceptualisation (development of research idea and aims), project management, determination of methodology, conducting research, conducting analyses, data curation, resources, visualization, writing article, reviewing and editing. **Matthieu Joseph Pedergnana**: Conceptualisation (development of research idea and objectives), conducting research, Data curation, review, and editing.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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Mobilya ve Ahşap Malzeme Araştırmaları Dergisi
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Cennet ağacından (*Ailanthus altissima* (Mill.) Swingle) elde edilen yapısal ahşabın Avrupa standartlarına göre mukavemet sınıflandırması

Fatih Kurul[1]*

ÖZ: Hızlı gelişen ve istilacı bir tür olan cennet ağacı (*Ailanthus altissima* (Mill.) Swingle) odunundan elde edilen farklı boyutlardaki yapısal tahtalar (toplam 163 adet) öncelikle DIN 4074-5 (2008) standartlarına göre görsel olarak sınıflandırılmıştır. Sonrasında vibrasyon yöntemi kullanılarak tahribatsız testler yapılmış ve son olarak TS EN 408 (2014) standardına göre 4-noktalı eğilme testleri gerçekleştirilmiştir. Bu test sonuçlarından elde edilen verilerle görsel ve makine mukavemet sınıfları belirlenmiştir. Tahribatsız testler sonucunda ortalama dinamik elastikiyet modülü 17838 MPa bulunmuştur. Mekanik testlerde ise ortalama eğilme direnci 96,6 MPa ve elastikiyet modülü 16647 MPa olarak tespit edilmiştir. Görsel mukavemet sınıflandırmasında, LS13 ve ret olmak üzere iki görsel sınıf belirlenmiştir. LS13 sınıfındakiler D50 mukavemet sınıfına atanırken, reddedilen tahtalar için bir mukavemet sınıfı karşılığı belirlenememiştir. D50 mukavemet sınıfını belirleyen özellik karakteristik yoğunluk değeri olmuştur. Makine mukavemet sınıflandırmasında, D60-D55-D50-Ret ideal makine ayarları yapılmış ve TS EN 14081-2 (2022) standardına göre doğruluğu onaylanmıştır. Makine mukavemet sınıflandırması, yüksek verim ve daha yüksek mukavemet sınıflarına ulaşılması nedeniyle görsel mukavemet sınıflandırmasından daha avantajlı bulunmuştur. Yapısal kullanım için yüksek potansiyele sahip bu türün, plantasyon ormancılığında alternatifler arasında değerlendirilmesi gerektiği düşünülmektedir.

Anahtar kelimeler: Cennet ağacı, Görsel ve makine sınıflandırması, Yapısal karakterizasyon

Strength grading of structural wood obtained from the tree of heaven (*Ailanthus altissima* (Mill.) Swingle) according to European standards

ABSTRACT: Structural boards (163 pieces in total) of different sizes obtained from the wood of the tree of heaven (*Ailanthus altissima* (Mill.) Swingle), a fast-growing and invasive species, were first visually graded according to DIN 4074-5(2008) standards. Then, non-destructive tests were performed using the vibration method, and finally, 4-point bending tests were performed according to the TS EN 408(2014) standard. Visual and machine strength grades were determined with the data obtained from these test results. As a result of the non-destructive tests, the average dynamic modulus of elasticity was 17838 MPa. In the mechanical tests, the average bending strength was determined as 96.6 MPa, and the modulus of elasticity was 16647 MPa. In the visual strength grading, two visual classes were determined: LS13 and reject. While those in the LS13 grade were assigned to the D50 strength class, a strength class could not be determined for the rejected boards. The characteristic density was the feature that determined the D50 strength class. In the machine strength grading, ideal machine settings were determined as D60-D55-D50-Reject, and the accuracy was verified according to the TS EN 14081-2 (2022) standard. The machine strength grading was found to be more advantageous than the visual strength grading due to its higher efficiency and ability to reach higher strength grades. This species, which has high potential for structural use, should be evaluated for alternative uses in plantation forestry.

Keywords: Tree of heaven, Visual and machine strength grading, Structural characterization

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1 Giriş

Ahşap yapılar, geçmişte ülkemizde sıkça tercih edilen yapı türlerinden olsa da yaşanan büyük yangınlar, malzeme hakkında yetersiz bilgi, ormanların azalacağı düşüncesi ve hızlı kentleşme gibi sebeplerden dolayı yerini betonarme yapılara bırakmıştır (Gezer ve ark., 2021). Günümüzde ahşap kullanımı, özellikle sürdürülebilirlik ve çevresel etki bakımından tekrardan önem kazanmaktadır. Ahşap, yenilenebilir bir kaynak olarak doğal döngüye katkıda bulunur ve karbondioksit depolama kapasitesine sahiptir. Bu husus, dünyada problem haline gelen iklim değişikliğiyle mücadelede önemli bir rol oynar. Ayrıca, ahşap malzeme inşaat sektöründe, enerji verimliliği sağlayan ve çevre dostu alternatifler sunan bir seçenek olarak öne çıkmaktadır. Ahşap, düşük karbon ayak izi ve biyolojik çeşitliliği koruma özellikleriyle, yapısal kullanım için aranan bir malzeme konumuna gelmiştir. Bu nedenlerle, ahşap malzeme kullanımı, gelecekteki sürdürülebilir kalkınma hedeflerine ulaşmada kritik bir öneme sahiptir. Ancak doğal bir malzeme olan ahşap anizotropik bir yapıya sahiptir. Çeşitli kusurları içermesi nedeniyle ahşap aynı tür içerisinde bile çeşitli fiziksel ve mekanik özelliklere (varyasyona) sahip olabilir. Bu nedenle ülkelerin belirledikleri yönetmelik ve standartlara uygun olarak inşaat sektörü uygulamalarında yalnızca mukavemet sınıfı belirlenmiş yapısal ahşap kullanılabilir. Böylece hem yapısal güvenliğin sağlanması hem de malzemenin ekonomik kullanımı hedeflenmektedir (Ridley-Ellis ve ark., 2016; Kurul ve As, 2024; Kurul ve ark., 2024).

Her ülke, ahşabı yapısal olarak sınıflandırmak için ulusal standartlar geliştirerek kendi yapısal sınıflandırma sistemini oluşturmuştur. Ülkemizde iğne yapraklı ağaç türlerinin yapısal görsel sınıflandırması için TS 1265 (2012) standardı kullanılmaktadır. Geniş yapraklı ağaç türleri için ise standart oluşturma çalışmaları devam etmektedir. Çok farklı ağaç türleri olması, yetişme yeri farklılıkları ve ülkelerin farklı sınıflandırma kuralları olması nedeniyle Avrupa yapısal ahşap sınıflandırma sistemi önerilmektedir. Bu sistem, TS EN 14081-1 (2019), TS EN 14081-2 (2022), TS EN 14081-3 (2022) ve destekleyici standartlardan oluşmaktadır. Tüm ulusal standartlar, bu sistemdeki asgari koşulları karşılamak zorundadır. Yapısal ahşap üç temel özelliğe göre mukavemet sınıflarına ayrılır. Bunlar mukavemet (eğilme veya çekme direnci), elastikiyet modülü (eğilme veya çekmede elastikiyet modülü) ve yoğunluktur. TS EN 338 (2016) standardı mukavemet sınıflarını ve özelliklerini iğne ve geniş yapraklı ağaçlara göre ayrı ayrı belirtmektedir. TS EN 1912 (2024) standardı ise ilgili tüm ülkelerin ulusal görsel sınıflandırma standartlarına göre belirlediği mukavemet sınıflarını listeler. Böylece farklı ülkeler arasında yapısal ahşap alışverişinin gerçekleşmesi sağlanmaktadır. (Stapel ve Kuilen, 2014; Ridley-Ellis ve ark., 2016). Günümüzde yapısal ahşap sınıflandırması için görsel sınıflandırma ve makine sınıflandırması olmak üzere iki sistem bulunmaktadır. Ahşabın mukavemetini etkileyen budaklar, lif kıvrıklığı, öz, çatlaklar, yıllık halka genişliği vb. parametreleri ölçmeye dayanan görsel sınıflandırma yöntemi eski zamanlardan günümüze kadar uzanmaktadır (Stapel ve Kuilen, 2014; Arriaga ve ark., 2022; Kurul ve As 2024). Makine sınıflandırmasında ise her parça tahribatsız yöntemlerle mekanik olarak değerlendirilir ve tahribatsız cihaz tarafından bir veya daha fazla fiziksel-mekanik özellik ölçülür. Sınıflandırma süresinin daha hızlı olması, insandan kaynaklanacak hatalarının en aza indirilmesi ve daha yüksek mukavemet sınıfları elde etme potansiyeli gibi nedenlerden dolayı makine sınıflandırmasını görsel sınıflandırmaya göre daha avantajlı bulunmaktadır (Brunetti ve ark., 2016; Nocetti ve ark., 2016; Ravenshorst ve Kuilen, 2016; Ridley-Ellis ve ark., 2016; Moltini ve ark., 2022; Kurul ve As, 2024).

Ülkemiz ormanlarında meşe, kayın gibi geniş yapraklı, karaçam, kızılçam, sarıçam, göknar, ladin ve sedir gibi iğne yapraklı asli ağaç türlerimiz orman varlığımızın yaklaşık

%97'sini oluşturmaktadır (OGM 2020). Ormanlarımız üzerindeki üretim baskısını azaltmak için bu türlere alternatif olarak hızlı büyüyen türlerin belirlenmesi ve kullanımının artırılması gerekmektedir. Çeşitli habitatlarda gelişme ve çok çeşitli toprak türlerinde büyüme yeteneğine sahip, oldukça hızlı büyüyen cennet ağacı (*Ailanthus altissima* (Mill) Swingle) ülkemizde plantasyon ormancılığı için önemli bir potansiyele sahiptir. Cennet ağacı, bozulmuş habitatlarda bile hızlı büyüyen, istilacı, çok çeşitli sıcaklık ve nem seviyelerine, kötü hava ve toprak şartlarına dayanıklı, önemli böcek ve hastalık sorunları görünmeyen bir ağaç türüdür (Asaro ve ark., 2009; Kowarik ve Saumel, 2007). Negi ve ark., (2000) yaptığı çalışmada Ailanthus'tan elde edilen kaplamaların LVL yapımına uygun olduğunu, Elbadawi ve ark., (2015) yongalevha üretimi için umut vadeden bir hammadde olabileceği sonucuna varmıştır. Bulgaristan'da yapılan çalışmalarda ise cennet ağacının kağıt ve mobilya üretiminde başarıyla kullanılabilen, hızlı büyüyen bir tür olduğunu ve zengin bir kaynak olarak kabul edilebileceği, dahası düşük maliyetli bir hammadde olduğunu ve deneysel plantasyonların kurulmasının uygun olduğu sonucuna varılmıştır. (Panayotov ve ark., 2001; Kozuharova ve ark., 2014). Bütün bu özellikleri düşünüldüğünde cennet ağacı her tür iklim ve çevresel koşullara uyum sağlayabilmesi, hızlı büyümesi, görece sert ve dirençli bir oduna sahip olması nedeniyle yapısal ahşap ve ahşap esaslı ürünlerin üretiminde avantajlı bir tür olarak karşımıza çıkmaktadır.

Bu çalışmanın amacı, cennet ağacından elde edilen yapısal tahtalar için Avrupa standartlarına göre görsel ve makine mukavemet sınıflarını belirlemek, görsel ve makine sınıflandırmasından elde edilen mukavemet sınıflarını karşılaştırmak ve seçilen yöntem ve parametreler için TS EN 14081 prosedürlerinin nasıl uygulanacağını göstererek benzer çalışmalara temel oluşturmaktır.

2 Materyal ve Metot

2.1 Materyal

Bu çalışmada, İstanbul Üniversitesi-Cerrahpaşa Araştırma ormanından (İstanbul/Türkiye) kesilen ortalama 17 yaşındaki cennet ağacı (*Ailanthus altissima* (Mill.) Swingle) odunundan elde edilen tahtalar kullanılmıştır. Taslak halinde biçilen tahtalar %12 denge rutubetine kadar kurutulmuştur. Sonrasında en kötü kusur tahtaların ortasında kalacak şekilde 20x40x780 mm, 30x40x780 mm, 20x50x1000 mm ve 30x50x1000 mm (genişlik x yükseklik x uzunluk) net ölçülere biçilerek toplam 163 adet yapısal tahta elde edilmiştir. Yapısal tahtaların rutubet miktarı, TS EN 13183-2 (2002) standardında tanımlanan prosedür takip edilerek direnç tipi rutubet ölçerle belirlenmiştir. Yapısal tahtaların ortalama rutubet miktarı %13,2 olarak tespit edilmiştir. Çizelge 1'de elde edilen örneklere ait bilgiler yer almaktadır.

Çizelge 1. Cennet ağacından elde edilen yapısal tahtaların kesit ölçüleri ve adetleri

Tür	Kesit Ölçüleri (mm)	Adet	Rutubet Miktarı (%)
Cennet Ağacı	20x40x780	39	13,2
	30x40x780	41	
	20x50x1000	42	
	30x50x1000	41	
	Toplam	163	

2.2 Metot

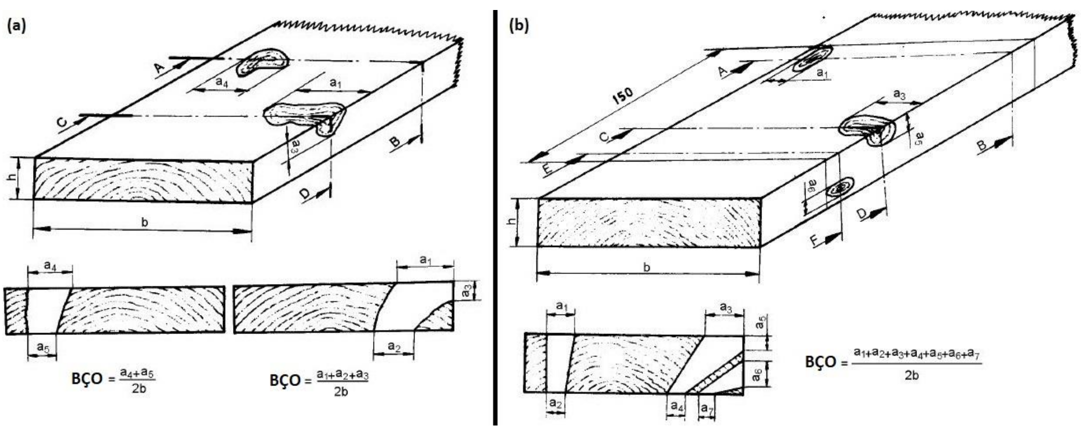
Bu çalışmada, elde edilen toplam 163 yapısal tahta üzerinde sırasıyla; DIN 4074-5 standardına göre görsel sınıflandırma, vibrasyon metodu kullanılarak tahribatsız değerlendirme, TS EN 408 (2014) standardına göre de tahribatlı eğilme testleri yapılmıştır. Elde edilen veriler kullanılarak Avrupa standardına göre görsel ve makine mukavemet sınıfları belirlenmiştir. Aşağıda sırasıyla tüm prosedürler detaylı şekilde açıklanmıştır.

2.2.1 Görsel sınıflandırma

Yapısal tahtalar için bazı görsel sınıflandırma kriterleri, DIN 4074-5 (2008)'e göre Çizelge 2'de tanımlanmıştır. Ülkemizde geniş yapraklı ağaçlardan elde edilen yapısal ahşapların görsel sınıflandırması için bir standart bulunmadığı için bu standart tercih edilmiştir. İğne yapraklı ağaç görsel sınıflandırma standardımızın DIN 4074-1 standardı ile çok benzer olması da bu standardın seçilmesinin bir başka gerekçesini oluşturmuştur. Budak çapı oranı (BÇO), budak çapının tahta genişliğinin iki katına bölünmesiyle elde edilmektedir. Bu nedenle, budaklar tüm tahta boyunca görsel olarak belirlenmiş ve en büyük paralel çapa sahip budaklar tespit edilmiştir. İlgili standarda göre budaklar tekli ve toplu budaklar olarak ikiye ayrılmaktadır. Tekli budaklar Şekil 1a, toplu budaklar ise Şekil 1b'de gösterildiği gibi ölçülmüştür. Budak çapı, her iki durum için de budağın bulunduğu yüzey eksine paralel uzunluğu olarak kabul edilmiştir. Ayrıca, lif kıvrıklığı, yıllık halka genişliği ve diğer kusurlar DIN 4074-5 (2008)'de belirtildiği şekilde ölçülmüştür.

Çizelge 2. DIN 4074-5 standardına göre yapısal tahta sınıflandırma kriterleri

Sınıflandırma Kriterleri	Sınıflar		
	LS 7 (Sınıf 3)	LS 10 (Sınıf 2)	LS 13 (Sınıf 1)
Tekli budak	0,50	0,33	0,20
Toplu budak	0,66	0,50	0,33
Lif kıvrıklığı	%16	%12	%7
Yıllık halka genişliği	-	-	-



Şekil 1. DIN 4074-5 (2008) standardına göre yapısal tahtalarda budak ölçüm metotları: (a) tekli budak ve (b) toplu budak

2.2.2 Tahribatsız değerlendirme

Görsel değerlendirmeden sonra, dinamik elastikiyet modülü (MOE_d) boyuna vibrasyon yöntemi kullanılarak belirlenmiştir. İlk olarak örneklerin en kesit ölçüleri 0.01 mm hassasiyetli kompasla, boyları ise metre yardımıyla ölçülerek kaydedilmiştir. Boyuna vibrasyon yöntemi, doğal frekansı (rezonans frekansı) ölçen bir yöntemidir. Test düzeneği Şekil 2'de gösterilmiştir. Test prosedüründe, örnekler yumuşak poliüretan yastıkla desteklenmiş iki mesnet üzerine yerleştirilir. Mesnetlerden birinde tartı vardır ve her bir parçanın kütlesi de bu şekilde kaydedilir. Bir çekiç yardımıyla numunenin bir ucundan vurulur ve stres dalga oluşturulur. Bu dalga test parçasının diğer ucuna kadar örneğin hacminin tamamını tarayarak ilerler. Diğer uca yerleştirilen bir mikrofon vasıtasıyla yakalanarak bilgisayara aktarılır. Hızlı Fourier dönüşümü (FFT) programı ile sesin doğal frekansı belirlenir. Sonrasında vibrasyon yöntemi için dinamik elastikiyet modülü ($MOE_{d,vib,\%12}$) Denklem 1'e göre hesaplanmaktadır.

$$MOE_{d,vib,\%12} = \frac{(2f_0 l)^2 \rho}{1-0.01(u-12)} 10^{-6} \quad (1)$$

Burada; $MOE_{d,vib,\%12}$ dinamik elastikiyet modülü (MPa), f_0 doğal frekans (Hz), l numunenin uzunluğu (m), ρ numunenin yoğunluğu (kg/m^3) ve u direnç tipi rutubet ölçer ile elde edilen rutubet miktarı (%).

Şekil 2. Boyuna vibrasyon test düzeneği

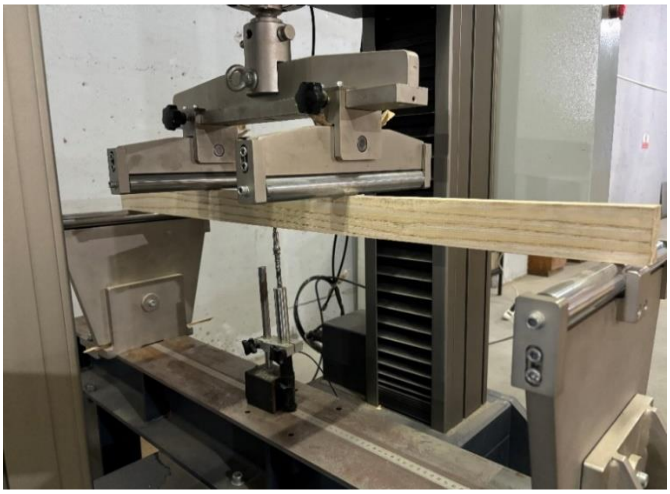
2.2.3 Mekanik testler

Görsel değerlendirme ve tahribatsız testlerden sonra, 163 adet yapısal tahta, TS EN 408 (2014)'de öngörülen 4-noktalı eğilme test düzeneğinde, 40 mm genişlikteki tahtalar için 720 mm ve 50 mm genişliktekiler için ise 900 mm mesnet açıklığında geniş yüzeye paralel (edgewise) kuvvet uygulanarak test edilmiştir. Testler, 50 kN yük kapasiteli üniversal test makinesi (BCO-DC300/LDL; BESMAK, Ankara, Türkiye) ile yapılmıştır. Deformasyonlar (w), 0.0001 mm hassasiyetli tek bir Lineer Değişken Diferansiyel Transformatör (LVDT) ile ortadan ölçülmüştür (Şekil 3). Testler 300 ± 120 saniyede tamamlanmıştır. Testler sonucunda elde edilen verilere göre, global elastikiyet modülü ($E_{m,g}$) ve eğilme direnci (f_m) sırasıyla Denklem 2 ve 3 ile belirlenmiştir.

$$E_{m,g} = \frac{3al^2 - 4a^3}{2bh^3\left(2\frac{w_2 - w_1}{F_2 - F_1} - \frac{6a}{5Gbh}\right)} \quad \mathrm{N/mm^2} \tag{2}$$

$$f_m = \frac{3Fa}{bh^2} \ \mathrm{N/mm^2} \tag{3}$$

Burada; $E_{m,g}$ global elastikiyet modülü (MPa), f_m eğilme direnci (MPa), l mesnetler arasındaki açıklık 18h (mm), a yükleme başlığının en yakın mesnete olan uzaklığı 6h (mm), F_2 - F_1 maksimum yükün %40'ı ve %10'undaki yük farkı (N), w_2 - w_1 maksimum yükün %40'ı ve %10'undaki deformasyonlar arasındaki fark (mm), G makaslama modülü (sonsuz olarak alınmıştır MPa), b örnek genişliği (mm) ve h örnek yüksekliğidir (mm).



Şekil 3. TS EN 408 (2014) standardına göre 4 noktalı eğilme test düzeneği

Mekanik testlerden sonra, her örnekten kırılma bölgesine yakın tam kesit ölçüsünde ve 20-40 mm uzunluğunda rutubet ve yoğunluk örnekleri kesilmiştir. Kesilen parçalar hemen 0,01 g hassasiyetli tartıda tartılmış ve boyutları da 0,01 mm hassasiyetli kompasla ölçülerek yoğunlukları hesaplanmıştır. Ayrıca, aynı örnekler üzerinde TS EN 13183-1 (2002)'de tanımlanan tam kuru ağırlık metoduna göre rutubetleri belirlenmiştir (Şekil 4).

Şekil 4. Tahribatlı testlerden sonra kesilen yoğunluk ve rutubet örneklerinin kurutulması

2.2.4 Görsel ve makine mukavemet sınıflandırması

Görsel ve makine mukavemet sınıflandırması karakteristik değerlerini belirlenmeden önce TS EN 384 (2022) standartlarına göre bazı düzeltmeler yapılmalıdır. Bunlardan ilki rutubet tahvilidir. %12 rutubet miktarında olmayan numunelerin elastikiyet modülü ve yoğunluk değerleri aşağıdaki formüller kullanılarak tahvil edilmiştir (Denklem 4 ve 5). Mevcut standart, eğilme direnci için bir tahvil işlemi ön görmemektedir.

$$Em, g\%12 = MOE(u) \times \left[1 + 0.01 \times \ (u - u_{ref})\right] \tag{4}$$

$$\rho_{\%12} = \rho(u) \times \left[1 - 0.005 \ \times \ (u - u_{ref})\right] \tag{5}$$

Burada; u, test anındaki rutubet miktarı (%8 ≤ u ≤ %18) ve u_{ref}, referans rutubet miktarı (%12).

Daha sonra tahta genişliği 150 mm'den küçük olduğu için eğilme direnci 6. denklem kullanılarak k_h faktörüne bölünmüştür. Elastikiyet modülü global olarak ölçüldüğünden 7. denklem kullanılarak lokal elastikiyet modülüne dönüşümü yapılmıştır.

$$k_h = Min\begin{cases}\left(\frac{150}{h}\right)^{0.2} \\ 1.3\end{cases} \tag{6}$$

$$E_0 = E_{m,g\%12} \times \ 1.3 - 2690 \tag{7}$$

Gerekli tahvil işlemleri tamamlandıktan sonra, cennet ağacından elde edilen yapısal tahtalar için TS EN 14358 (2016) standardı kullanılarak %5'lik eğilme direnci (karakteristik eğilme direnci) $f_{05,i}$, %5'lik yoğunluk (karakteristik yoğunluk) $\rho_{05,i}$ ve ortalama elastikiyet modülü değerleri belirlenmiştir.

Makine mukavemet sınıflandırmasında, eğilme direnci, elastikiyet modülü ve yoğunluk değerleri, sınıf belirleyen özellikler (GDP, grade-determining properties) olarak ve dinamik elastiklik modülü ($MOE_{d,vib,\%12}$) değeri ise gösterge özellikleri (IP, indicating properties) olarak kullanılmıştır. Makine mukavemet sınıflandırması için, tüm tahtalar TS EN 338 (2018)'deki bir mukavemet sınıfına atanmıştır. Belirlenen mukavemet sınıflarına ait karakteristik değerler TS EN 384 (2022)'ye göre hesaplanmıştır. Hesaplama yapılırken eğilme direnci ve yoğunluk için %5'lik değer (sıralama yöntemi) ve elastikiyet modülü için ise ortalama değerler kullanılmıştır. Sırasıyla boyut matrisi, temel ağırlıklandırma matrisi ve genel ağırlıklandırma matrisi TS EN 14081-2 (2022)'ye göre hesaplanmıştır. Sonrasında genel ağırlıklandırma matrisinde yanlışlıkla üst ve alt mukavemet sınıfına atanan parçalara karşılık gelen hücrelerin 0,4'ü aşıp aşmadığı kontrol edilmiştir. Tüm hücrelerdeki değerlerin 0,4'den daha düşük olduğu görüldükten sonra ilgili mukavemet sınıflarına göre makine ayarları hesaplanmıştır. Görsel ve makine mukavemet sınıflandırmasında alt örneklem grupları kullanılmadığı için bunlara ait katsayılar hesaplamalarda ihmal edilmiştir.

2.2.5 İstatistik hesaplamalar

Örneklere ait ortalama, standart sapma ve varyasyon katsayı değerleri IBM SPSS Statistic 29.0 programı kullanılarak hesaplanmıştır. Ayrıca makine mukavemet sınıflandırmasında kullanılmak üzere dinamik elastikiyet modülü + budak çapı oranı – eğilme direnci, dinamik elastikiyet modülü – global elastikiyet modülü ve dinamik elastikiyet modülü – yoğunluk parametreleri arasında regresyon analizi yapılarak bunlardan elde edilen verilerle makine ayarları yapılmıştır.

3 Bulgular ve Tartışma

Görsel sınıflara göre örnek sayısı, rutubet miktarı, %12 rutubete tahvil edilmiş yoğunluk, %12 rutubete tahvil edilmiş dinamik elastikiyet modülü, %12 rutubete tahvil edilmiş global elastikiyet modülü ve eğilme direnci ortalama değerleri Çizelge 2'de verilmiştir. Ayrıca değerlerin altında parantez içinde varyasyon katsayıları gösterilmiştir.

Çizelge 2. Test örneklerinde görsel sınıflara göre tahribatsız ve tahribatlı test sonuçları

Görsel Sınıf	Adet	Rutubet Miktarı (%)	ρ_{12} (kg/m^3)	$MOE_{d,vib,\%12}$ (MPa)	$E_{m,g,\%12}$ (MPa)	f_m (MPa)
LS 13	158	12,2 (8.5)	678 (4,7)	17941 (8,9)	16758 (9,0)	97,7 (10,3)
Ret	5	12,7 (8,8)	677 (2,0)	14577 (18,9)	13138 (16,8)	60,6 (40,9)
Toplam	163	12,2 (8,5)	678 (4,6)	17838 (9,9)	16647 (10,0)	96,6 (13,1)

Brandner ve Schickhofer (2010) yaptıkları çalışmada kusursuz cennet ağacı örneklerinde EN 408 standardına göre 4 noktalı eğilme testleri yapmış ve ortalama eğilme direncini 105,6 MPa, elastikiyet modülünü 14590 MPa ve yoğunluk değerini 656 kg/m^3 olarak tespit etmişlerdir. Yine aynı çalışmada yapısal cennet ağacı örnekleri üzerinde 4-noktalı eğilme testleri gerçekleştirilmiş fakat kusurlar net bir şekilde tanımlanmamıştır. Bu deneylerde ise ortalama eğilme direncini 51,3 MPa, elastikiyet modülü 12420 MPa ve yoğunluk değerini 646 kg/m^3 olarak tespit etmişlerdir. Ayrıca kusursuz cennet ağacı örneklerinden elde edilen değerleri kusursuz dişbudak örnekleriyle karşılaştırdıklarında bu iki ağaç türünün fiziksel ve mekanik özelliklerinin yakın olduğu sonucuna varmışlardır. Szabolcs ve Varga (2021) yaptığı çalışmada ise kusursuz cennet ağacı örnekleri üzerinde 3 noktalı eğilme testleri yapmış ve sırasıyla ortalama eğilme direnci, elastikiyet modülü ve yoğunluk değerlerini 112 MPa, 11665 MPa ve 702 kg/m^3 olarak tespit etmiştir.

DXX mukavemet sınıfı, geniş yapraklı ağaç türlerinde geniş yüzeye paralel eğilme mukavemetini tanımlamaktadır. DIN 4074-5 (2008) standardına göre görsel sınıflandırılan cennet ağacı yapısal tahtaların karakteristik mukavemet değerleri ve TS EN 338 standardına göre mukavemet sınıfları, Çizelge 3'de verilmiştir.

Çizelge 3. Yapısal tahtaların karakteristik mukavemet değerleri ve sınıfları

Karakteristik Değerler	Eğilme Direnci (MPa)				Elastikiyet Modülü (GPa)		Yoğunluk (kg/m^3)			Mukavemet Sınıfı
Direnç Sınıfı	Ort.	V.K (%)	P/NP	$f_{05,i}$	$E_{0,ort}$	V.K (%)	Ort.	V.K (%)	$\rho_{05,i}$	
LS 13	76,9	10,7	NP	62,3	19,4	10,2	678,0	4,7	621,6	D50
Sınıf Dışı	46,6	45,7	NP	10,9	14,4	22,2	676,8	2,2	639,9	-

Çizelge 3 incelendiğinde LS 13 (Sınıf 1) olarak sınıflandırılan yapısal tahtalar eğilme direnci karakteristik değerine göre D60, ortalama elastikiyet modülü değerine göre D65 ve karakteristik yoğunluk değerine göre ise D50 olarak sınıflanmaktadır. Bu üç özellikten en kötüsüne göre mukavemet sınıfı belirlendiği için LS 13 görsel sınıfının karşılığı D50 olarak belirlenmiştir. TS EN 1912 (2024) standardı incelendiğinde D50 mukavemet sınıfında İngiliz görsel sınıflandırma standardına göre TH1 görsel sınıfındaki Amerikan beyaz meşesi ve bazı tropik ağaç türleri görülmektedir. İtalyan standardına göre LS1 görsel sınıfındaki kayın D45 ve yine İngiliz TH1 görsel sınıfındaki Amerikan kırmızı meşesi D40 olarak görülmektedir. Yapısal performans bakımından bu türlerle karşılaştırdığımızda cennet ağacının potansiyeli daha net anlaşılmaktadır.

Makine sınıflandırması için cennet ağacı yapısal tahtalarına ait makine ayarları vibrasyon yöntemi (IP) ve eğilme direnci, global elastikiyet modülü ve yoğunluk (GDP) olarak belirlenmiştir. Makine ayarları Çizelge 4’te verilmiştir.

Çizelge 4. IP ve GDP’ler kullanılarak elde edilen makine ayarları

IP	GDP	R^2	Denklem	F Değeri	Önem Düzeyi
$MOE_{d, vib,\%12}$ +BÇO	f_m	0.444	0.003*IP+31.2-32.5*BÇO	63.890	0.001
	$E_{m, g,\%12}$	0.644	0.987*IP+1652.1	291.101	0.001
	$\rho_{\%12}$	0.000	-	0	0.983

Yapısal tahtalar için ideal mukavemet kombinasyonu D60-D55-D50-Ret (R) olarak belirlenmiştir. Çizelge 4’teki ayarlara göre hesaplanmış eğilme direnci, elastikiyet modülü ve yoğunluk değerlerine göre oluşturulan boyut matrisi Çizelge 5’de verilmiştir. Çizelge 4’te görüldüğü üzere, dinamik elastikiyet modülü ($MOE_{d,vib,\%12}$) ile yoğunluk ($\rho_{\%12}$) arasında korelasyon bulunmamıştır ($R^2 = 0{,}000$). Bu düşük korelasyon, cennet ağacının hızlı büyüyen bir tür olmasından kaynaklanabilir. Hızlı büyüyen türlerde, yıllık halka genişliği ve odun dokusundaki varyasyonlar, yoğunluğun elastikiyet modülü ile zayıf bir ilişki göstermesine neden olabilir (Ridley-Ellis ve ark., 2016). Ayrıca, örneklerin genç odundan meydana gelmesi, odun yoğunluğunun daha düşük ve değişken olmasına yol açmış olabilir. Szabolcs ve Varga (2021) yaptıkları çalışmada cennet ağacında yoğunluk ile mekanik özellikler arasında zayıf bir ilişki rapor etmemiştir, bu da bu bulgunun türe özgü olabileceğini düşündürmektedir.

Çizelge 5. IP ve GDP’lere göre oluşturulan boyut matrisi.

Yöntem	Uygun Sınıf	Atanmış Sınıf			
		D60	D55	D50	R
Vibrasyon	D60	29	1	0	0
	D55	2	81	1	0
	D50	2	4	27	2
	R	0	0	2	12
	Total	33	86	30	14

Uygun ve atanmış mukavemet sınıfları dikkate alınarak oluşturulan temel ağırlıklandırma matrisi Çizelge 6’da verilmiştir.

Çizelge 6. IP ve GDP'lere göre oluşturulan temel ağırlıklandırma matrisi.

Uygun Sınıf	Atanmış Sınıf D60	D55	D50	R
D60	0	0.31	0.67	2.00
D55	0.30	0	0.35	1.56
D50	0.67	0.33	0	1.11
R	1.74	1.39	1.01	0

Boyut matrisi ve temel ağırlıklandırma matrisinin çarpılıp ilgili sütundaki toplam miktara bölünmesiyle elde edilen genel ağırlıklandırma matrisi Çizelge 7'de verilmiştir.

Çizelge 7. IP ve GDP'lere göre oluşturulan genel ağırlıklandırma matrisi.

Yöntem	Uygun Sınıf	Atanmış Sınıf D60	D55	D50	R
Vibrasyon	D60	0.00	0.00	0.00	0.00
	D55	0.02	0.00	0.01	0.00
	D50	0.04	0.02	0.00	0.16
	R	0.00	0.00	0.07	0.00

İdeal mukavemet sınıfı kombinasyonuna (D60-D55-D50-R) ait karakteristik değerler ve her bir mukavemet sınıfına ait makine sınıflandırmasından elde edilen IP ayarları Çizelge 8'de verilmiştir.

Çizelge 8. İdeal mukavemet sınıfı kombinasyonuna ait karakteristik değerler ve IP ayarları

Karakteristik Değerler		Eğilme Direnci (MPa)				Elastikiyet Modülü (GPa)		Yoğunluk (Kg/m^3)			IP Ayarı (MPa)
Yöntem	Direnç Sınıfı	Ort.	V.K (%)	P/NP	$f_{05,i}$	$E_{0,ort}$	V.K (%)	Ort.	V.K (%)	$\rho_{05,i}$	
Vibrasyon	D60	79.1	6.8	NP	70.1	19.5	6.1	713.2	1.5	700.1	15551
	D55	78.7	8.7	NP	66.7	20.1	7.8	681.2	1.7	662.4	14031
	D50	71.6	14.6	NP	52.2	18.3	12.4	658.4	4.0	630.9	12511
	R	63.4	27.9	NP	29.9	16.4	19.0	631.9	8.5	568.8	-

Makine mukavemet sınıflandırması sonuçlarına göre, ideal sınıf kombinasyonu D60-D55-D50-R olarak belirlenmiş ve Çizelge 7 incelendiğinde hiçbir hücre 0,4'den daha büyük çıkmadığı ve Çizelge 8'e göre de her mukavemet sınıfı için hesaplanan karakteristik değerlerin o mukavemet sınıfını karşılaması sebebiyle ayarların uygunluğu onaylanmıştır. Ayrıca, makine mukavemet sınıflandırması görsel mukavemet sınıflandırmasıyla karşılaştırıldığında, makine mukavemet sınıflandırmasının verimi çok daha yüksek çıkmıştır. Görsel mukavemet sınıfında LS 13 görsel sınıfı karşılığında sadece D50 mukavemet sınıfına atanmasına rağmen, makine mukavemet sınıflandırmasında çok daha yüksek mukavemet sınıflarına atamalar gerçekleşmiştir. Bu nedenlerle makine dayanım sınıflandırması görsel dayanım sınıflandırmasına göre daha avantajlı olarak değerlendirilmektedir (Ridley-Ellis ve ark., 2016; Kurul ve As, 2024).

4 Sonuçlar ve Öneriler

Bu çalışma sonucunda elde edilen çıktılara göre;

- LS 13 ve R görsel sınıflar için karakteristik değerler hesaplanmıştır. Buna göre LS 13 görsel sınıfı D50 dayanım sınıfına atanmıştır. Sınıf dışı tahtalar ise herhangi bir dayanım sınıfına atanamamıştır. Bu dayanım sınıfları cennet ağacının yerli türlere güçlü bir alternatif oluşturacağı sonucunu ortaya koymaktadır.
- Makine mukavemet sınıflandırmasında, cennet ağacı için D60-D55-D50-R makine ayarları yapılmıştır. Buna göre, örneklerin %20'si D60, %53'ü D55, %18'i D50 ve %9'u R mukavemet sınıflarına atanmıştır. Bu oran görsel mukavemet sınıflandırmasında %97'si D50 ve %3'ü R şeklinde gerçekleşmiştir. Buna göre makine mukavemet sınıflandırmasında görsel mukavemet sınıflandırmasına kıyasla daha yüksek verimlilik elde edilmiştir. Özellikle, makine mukavemet sınıflandırmasının kullanılması, mukavemeti daha yüksek mühendislik ürünü ahşap malzemelerin (örneğin, Glulam ve CLT) üretilmesini sağlayacaktır.
- Hızlı büyüyen türlerde görsel mukavemet sınıflandırmasında karakteristik yoğunluk değeri bu çalışmada olduğu gibi görece düşük olacağı için elde edilecek mukavemet sınıfının daha düşük olmasına neden olacaktır. Bu nedenle hızlı büyüyen türlerde makine mukavemet sınıflandırmasının tercih edilmesi daha avantajlı bulunmaktadır.
- Makine mukavemet sınıflandırması, kullanılan en kesit ölçülerinin ±%10'unu kapsamaktadır. Bu çalışma sonucunda 18-22 mm, 27-33 mm kalınlık ve 36-44 mm, 45-55 mm genişlik aralığındaki cennet ağacı yapısal tahtaları yukarıda verilen IP ayarları kullanılarak makine sınıflandırması yapılabilmektedir. Bu ölçüler dışındaki bir ölçüde tekrardan makine ayarlarının yapılması gerekmektedir.
- Bundan sonra yapılacak çalışmalarda, diğer hızlı büyüyen türler için benzer prosedürler uygulanarak görsel ve makine mukavemet sınıflarının belirlenerek plantasyon çalışmaları yapılması, ormanlarımız üzerindeki baskıları süreç içerisinde azaltma potansiyeline sahiptir. Aynı zamanda iç piyasa için de yüksek kalitede yerli hammadde üretimi sağlanarak katma değeri yüksek yapısal ahşap malzemelerin üretilmesinin önünün açılacağı düşünülmektedir.

Yazar Katkıları

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Urban furniture design and ergonomic assessment in neighborhood parks: the case of Fabrika District, Diyarbakır, Türkiye

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ABSTRACT: Neighborhood parks are essential public spaces encouraging socialization, physical activity, and relaxation. Their effective use is closely tied to the ergonomic design of urban furniture. This study evaluates the ergonomic suitability of urban furniture in four parks in the Fabrika Neighborhood, Yenişehir District, Diyarbakır by using a qualitative assessment method. The research was conducted in four stages: (1) A literature review identified 13 sub-criteria under six main categories: material, ergonomics, inclusive design, color, safety, and vandalism. (2) Fieldwork conducted between November and December 2024 assessed 18 types of urban furniture using a 0–5 rating scale. (3) Parks were classified based on their ergonomic performance. (4) Recommendations were developed to enhance usability. The findings revealed that NP1 (42.1%), NP2 (42.0%), and NP3 (41.6%) were "moderately suitable" while NP4 (26.4%) was "less suitable." Deficiencies were particularly noted in ergonomics, safety, and inclusive design. Unlike previous studies, this research integrates ergonomic criteria for a comprehensive evaluation. Future studies should prioritize sustainable, technology-based solutions to enhance urban furniture design.

Keywords: Urban furniture, Ergonomics, Urban life quality, Neighbourhood parks

Mahalle parklarında kent mobilyası tasarımı ve ergonomik değerlendirme: Fabrika Mahallesi örneği, Diyarbakır-Türkiye

ÖZ: Mahalle parkları, sosyalleşme, fiziksel aktivite ve dinlenme imkânı sunan önemli kamusal alanlardır. Bu alanların etkin kullanımı, büyük ölçüde kent mobilyalarının ergonomik tasarımına bağlıdır. Bu çalışma, Diyarbakır ili Yenişehir ilçesi Fabrika Mahallesi'ndeki dört parkta (NP1, NP2, NP3 ve NP4) yer alan kent mobilyalarının ergonomik uygunluğunu nitel bir değerlendirme yöntemiyle incelemektedir. Araştırma dört aşamada yürütülmüştür: (1) Literatür taraması sonucunda malzeme, ergonomi, kapsayıcı tasarım, renk, güvenlik ve vandalizm olmak üzere altı ana başlık altında 13 alt kriter belirlenmiştir. (2) Kasım–Aralık 2024 tarihleri arasında sahada 18 farklı kent mobilyası türü 0–5 puanlama ölçeğiyle değerlendirilmiştir. (3) Parklar ergonomik uygunluk düzeylerine göre sınıflandırılmıştır. (4) Kullanılabilirliği artırmaya yönelik öneriler geliştirilmiştir. Bulgulara göre NP1 (%42,1), NP2 (%42,0) ve NP3 (%41,6) "orta düzeyde uygun," NP4 (%26,4) ise "düşük düzeyde uygun" bulunmuştur. Özellikle ergonomi, güvenlik ve kapsayıcı tasarım konularında eksiklikler tespit edilmiştir. Çalışma, ergonomik kriterleri içeren kapsamlı bir değerlendirme sunarak önceki araştırmalardan ayrılmaktadır. Gelecekteki çalışmalarda, kent mobilyası tasarımını geliştirmek için sürdürülebilir, teknoloji tabanlı çözümlere öncelik verilmelidir.

Anahtar kelimeler: Kent mobilyaları, Ergonomi, Kentsel yaşam kalitesi, Mahalle parkları

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1 Introduction

Cities require careful planning, particularly for public spaces, as these areas meet social, cultural, and physical needs. Neighborhood parks (NPs) with rapid urbanization have become vital to sustainable urban development, providing essential recreational spaces for residents (Gehl, 2011). These parks foster social interaction across diverse age and socio-economic groups while supporting physical and mental well-being (Brown and Gillespie, 1995). The ergonomic and design features of urban furniture in NPs play a significant role in ensuring the effective and sustainable use of these spaces. Furniture is expected to be user-friendly, accessible, durable, and adaptable to environmental conditions. Properly designed elements that follow ergonomic principles enhance user comfort and contribute to long-term urban resilience (Tilley, 2002). Moreover, the rise in vandalism incidents alongside urbanization necessitates a careful evaluation of materials and durability in urban furniture design (Olgun, 2013). Literature indicates that urban furniture is assessed based on functionality, aesthetics, ergonomics, materials, color, and resistance to vandalism (Şahin et al., 2019; Olgun, 2013; Arat, 2020; Yeler et al., 2022). Key factors influencing park usability include comfortable seating, safe playgrounds, and accessible sports equipment (Arat, 2020). However, effective use depends on the presence of such equipment and its placement, maintenance, and user-friendliness (UN-Habitat, 2016). Therefore, both qualitative and quantitative evaluations of park furnishings are essential for promoting public health and social cohesion.

Studies on materials emphasize the importance of durability, sustainability, and user preferences. Innovative materials, such as lightweight concrete, provide resilience and modular flexibility (Thamrin et al., 2018; Kara et al., 2024) while sustainability efforts promote the use of recyclable and non-toxic local materials (Şatiroğlu et al., 2023). Nonetheless, traditional materials like concrete and polypropylene still raise concerns over carbon emissions (Sipahi and Sipahi, 2024), and wood and plastic-based components are particularly vulnerable to vandalism. (Olgun, 2013; Şahin et al., 2019). Ergonomic design enhances user comfort, health, and park usability while color planning improves perception and navigation (Gamito and Silva, 2016) and human-centered designs increase comfort (Külekçi, 2018). Ergonomic assessment tools link furniture design to health outcomes (Appolloni et al., 2020) while accessibility remains crucial for all users (Arat, 2020). Color choice also significantly affects park furniture's visibility, identity, and satisfaction; uniform color schemes improve legibility (Mazaherian et al., 2020) while excessive variation causes visual clutter (Gamito and Silva, 2020). Harmonizing furniture colors with the natural environment enhances the user experience (Saeedi and Dabbagh, 2020). Additionally, Gamito and Sousa (2019) stressed the importance of grounding color planning in scientific principles by suggesting that regional color schemes should be developed through community and expert feedback. Inclusive design principles emphasize that urban furniture must serve users of all ages and physical abilities, and urban pathways must ensure accessibility for individuals with disabilities (Özdemir Işık et al., 2016). A study on Altındere Valley National Park highlighted how incompatible furniture negatively impacts user experiences in natural spaces, advocating for design modifications to improve environmental integration (Aksu, 2015). Finally, vandalism and safety are critical factors; physical deterioration discourages park usage (Bhaskaran et al., 2024; Douglas et al., 2018; Echeverría et al., 2014; Marquet et al., 2019) while traditional neighborhood designs and Crime Prevention Through Environmental Design (CPTED) principles improve security, but note the absence of systematic guidelines (Sohn et al., 2015). McCabe and Strauss (2022) reveal that vandalism in parks increases bullying, particularly among adolescents with asthma. Marquet et al. (2019) and Echeverría et al. (2014) find that higher crime rates near parks discourage children and young people from using these spaces and reduce physical activity. Well-maintained parks foster community bonds and improve safety perceptions (Suminski et al., 2015; Zhai et al., 2020).

This study aims to evaluate the ergonomic and design characteristics of urban furniture in four NPs in the Fabrika neighborhood of the Yenişehir district, Diyarbakır, Türkiye. The study identifies existing issues by examining the suitability of urban furniture in terms of materials, ergonomics, inclusive design, color, safety, and resistance to vandalism. Analyses have been conducted to propose recommendations for enhancing the functionality and inclusivity of NPs based on literature reviews and field observations. Unlike earlier studies that often focus on isolated aspects such as materials, ergonomics, color, safety, or vandalism, this research comprehensively assesses all key components of urban furniture. It introduces a systematic and adaptable methodology for evaluating ergonomic and design features across different green spaces. Furthermore, beyond theoretical analysis, the study provides empirical and practical recommendations for municipalities and urban planners. The study advances the existing literature, delivering a more holistic assessment of urban furniture to support the creation of more functional, inclusive, and sustainable NPs by integrating these aspects.

2 Materials and Methods

2.1 Study Area

This study examines the Fabrika Neighborhood in the Yenişehir district of Diyarbakır, a region characterized by high population density and strategic importance for urban development. Diyarbakır, located in southeastern Türkiye, has a population of 1,810,366, making it one of the country's fastest-growing cities (TÜİK, 2023) (Figure 1).

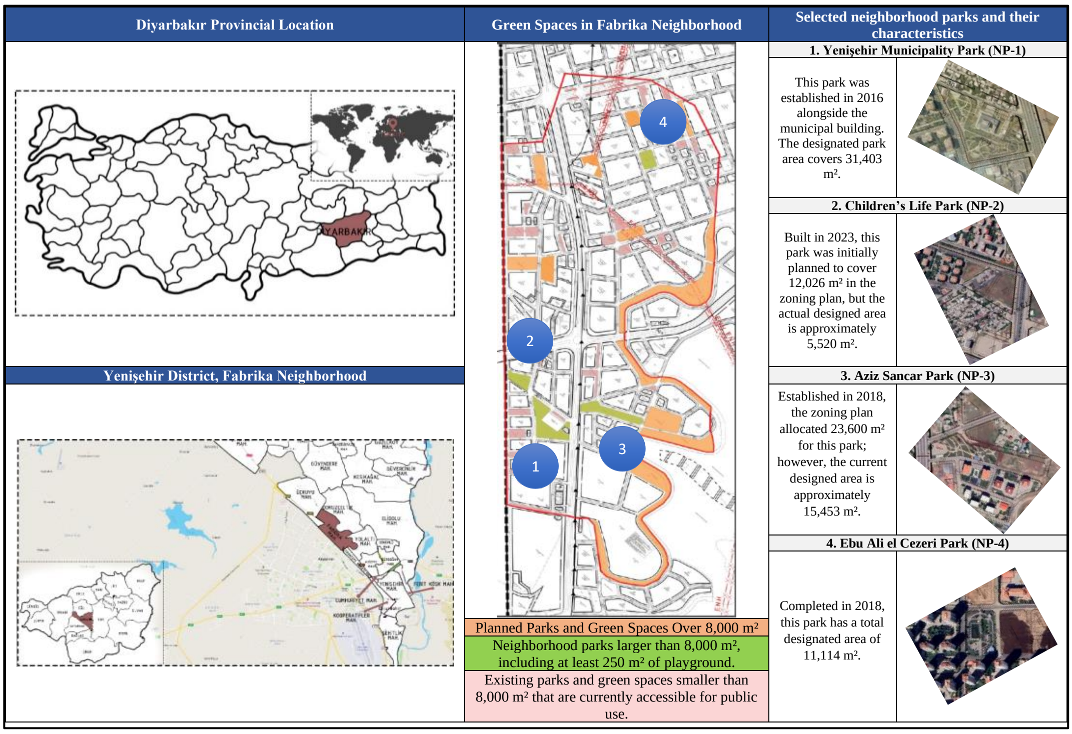

Figure 1. The study area of Diyarbakır, Turkey

The Yenişehir district, home to approximately 215,000 residents, is key in distributing green spaces and public furniture (TÜİK, 2023). Data from the Diyarbakır Yenişehir Municipality indicates that Fabrika Neighborhood contains 39 green spaces, covering 326,797.3 m², equating to 3,267.97 m² of green space per capita. These figures provide a basis for assessing the adequacy of green space distribution in line with urban planning standards. According to Yıldızcı (1982), NPs should have a minimum area of 8,000 m² while Uzun (1990) recommends that a playground within such a park should be at least 250 m². Among the 39 green spaces in Fabrika Neighborhood, 19 meet the minimum area requirement of

8,000 m²; however, only four meet both criteria. Therefore, this study focuses on the observation and analysis of these four parks: Yenişehir Municipality Park (NP-1), Children's Life Park (NP-2), Aziz Sancar Park (NP-3), and Ebu Ali el-Cezeri Park (NP-4) (Figure 1).

2.2 Methods

The research methodology consists of four main stages:

- Identifying the main and sub-criteria for evaluation through a literature review and expert opinions.
- Rating the characteristics of the evaluation criteria.
- Conduct field studies to assess the equipment in NPs and determine their suitability classifications.
- Developing recommendations based on the findings.

2.2.1 Determination of evaluation criteria

The criteria for evaluating the equipment in NPs reflect the park's fundamental structure. The condition of this structure, both in its entirety and components, reveals the park's qualitative and quantitative characteristics. In this context, the criteria for assessing the qualitative and quantitative attributes of NPs and their furniture were derived from national and international scientific studies (Table 1).

Table 1. Criteria used in the literature for evaluating urban furniture in NPs

Previous studies	**Aksu (2015)**	**Appolloni et al. (2019)**	**Arat (2020)**	**Bhaskaran et al. (2024)**	**Douglas et al. (2018)**	**Echeverria (2019)**	**Gamito and Silva (2016)**	**Gamito and Silva (2020)**	**Gamito and Sousa (2019)**	**Grabiec et al. (2022)**	**Özdemir Işık and ark. (2016)**	**İnak (2017)**	**Kahvecioğlu ve Sağlık (2023)**	**Kesik ve ark. (2014)**	**Külekçi (2018)**	**Lee (2021)**	**Marquet et al. (2019)**	**Mazaherian et al. (2020)**	**McCabe and Strauss (2022)**	**Olgun (2013)**	**Saeedi and Dabbagh (2020)**	**Sipahi and Sipahi (2024)**	**Sohn et al. (2015)**	**Suminski et al. (2015)**	**Şahin et al. (2019)**	**Şatıroğlu et al. (2023)**	**Thamrin et al. (2018)**	**Tilford Centers (2019)**	**Ünal and Uslu (2018)**	**Zhai et al. (2020)**
City/Country	Kastomonu, Türkiye	Rome, Italy	Konya, Türkiye	Delhi, Hindistan	Los Angeles, USA	Los Angeles, ABD	Lisbon, Portugal	Porto, Portugal	Lajes, Portugal	Warsaw, Poland	Trabzon, Türkiye	Ankara, Türkiye	Çanakkale, Türkiye	İstanbul, Türkiye	Ankara, Türkiye	New York, USA	Chicago, USA	Isfahan, Iran	NewYork, USA	Antalya, Türkiye	Tehran, Iran	İzmir, Türkiye	Busan, South Korea	Kansas, USA	Türkiye	İstanbul, India	Jakarta, Indonesia	Norfolk, USA	Adana, Türkiye	Beijing, China
Materials	+									+												+				+	+		+	
Ergonomic		+	+				+	+	+	+	+	+	+	+	+													+	+	
Color							+	+	+	+								+			+									
Inclusive design	+	+		+						+	+	+		+		+							+	+				+	+	+
Vandalizm and Security				+	+	+				+						+	+		+	+			+	+	+				+	

This study evaluated six main criteria and eleven sub-criteria determined through field research and expert consultations as outlined in Table 1. Since inclusive design and color did not fall under any specific category, they were added separately increasing the total number of evaluation criteria to thirteen. Given the variation in park furniture design, ergonomics, material selection, color harmony, inclusive design, vandalism resistance, and safety, a comprehensive approach was adopted to identify essential elements. Six distinct amenity groups were defined to ensure that NPs meet user expectations and function as sustainable public spaces. These groups encompass various types of urban furniture and recreational elements crucial for accessibility, comfort, and durability. A detailed ergonomic and functional assessment was conducted on nineteen different pieces of equipment within these groups (Table 2) providing insights into their suitability, deficiencies, and potential improvements for more user-friendly and inclusive public spaces.

Table 2. Evaluation criteria (left side) and furniture (right side)

EVALUATION CRITERIA	
MAIN CRITERIA	**SUB-CRITERIA**
Materials	Material type
	Material properties
	Surface materials
Ergonomic	Compliance with standards
Inclusive design	
Color	
Safety	Maintenance
	Infrastructural stability
	Safe design
Vandalism	Breaking and Shattering
	Cutting, Scratching, and Carving
	Burn
	Graffiti and Paint

FURNITURES	
Urban Furniture	Benches
	Gazebos/Pergolas
	Trash bins
	Lightings
	Information Boards
Water Features	Fountains
	Ornamental pools
Boundary	Walls
	Fences
	Vegetative boundaries
Playgrounds and Sports areas	Playgrounds
	Sports fields
Pathways	Pedestrian paths
	Bicycle lanes
	Vehicle roads/Parking areas
Others	Restrooms
	Security booth
	Sculptures/Art Installations

2.2.2 Rating of evaluation criteria

To evaluate the conditions of the 13 criteria listed in Table 2, each criteria was scored between 0 and 5 to identify the strengths and weaknesses of NPs furniture. Suitable characteristics were determined using sources from Table 1, expert opinions, and Turkish Standards Institution (TSE) guidelines which ensure national standards for product quality and safety (Appendix 1). The criteria were categorized into two groups: scalable and non-scalable. Scalable criteria covering multiple features were rated from 0 to 5. In contrast, non-scalable criteria were evaluated as "present/absent" or "suitable/unsuitable," receiving a score of 0 (absent/unsuitable), 3 (partially suitable), or 5 (present/suitable) depending on the degree of compliance. This method provides an objective and adaptable evaluation framework tailored to local conditions.

2.2.3 Determination of suitability classes

A quantitative and qualitative scoring method was employed to assess parks based on equipment quality, design, color harmony, accessibility, safety, and resistance to vandalism. The suitability percentage for each park was determined by dividing its total score by the maximum possible score. Parks were then categorized into five groups based on this percentage: least suitable (0–20%), less suitable (21–40%), moderately suitable (41–60%), suitable (61–80%), and most suitable (81–100%). This structured evaluation enabled the identification of deficiencies, assessment of overall functionality and safety, and guided improvements for more effective and user-friendly urban green spaces.

3 Results

3.1 Identifying Furniture and Features in Neighborhood Parks

This study assessed the condition of furniture and facilities in NPs located in the Fabrika Neighborhood, Yenişehir District, Diyarbakır. Fieldwork conducted between November and December 2024 evaluated the existing elements and identified deficiencies, detailed in Table 3, regarding materials and colors. The findings revealed several shortcomings: NP3 and NP4 lacked gazebos/pergolas; NP1, NP3, and NP4 were missing informational signs and panels; NP2, NP3, and NP4 had no fountains; NP1, NP2, and NP4 lacked pools. NP4 had no walls, NP1 and NP4 lacked fences, and none of the parks had vegetative boundaries. Sports facilities and bicycle paths were absent in NP2 and NP3, and none of the parks included vehicle roads or parking areas, which limited accessibility. Additionally, there was no toilet in NP1, no security booth in NP4, and no artistic sculptures in NP3 and NP4.

These deficiencies negatively affect comfort, safety, and usability of the parks and these diminish visitor satisfaction. Variations in materials and color choices also affect the visual appeal and functionality of the park. The absence of essential features such as signage, water elements, and recreational infrastructure underscores the need for standardized, inclusive, and comprehensive planning to improve accessibility and user experience in NPs.

Table 3. Material and color properties of furniture

FURNITURES	NPs / Furniture	NP1	NP2	NP3	NP4
					MATERIAL TYPES
URBAN FURNITURE	*Benches*	Metal+Wood	Concrete + Wood	Wood, Metal, Concrete	Concrete + Wood
	Gazebos/Pergolas	Wood	Wood		
	Trash bins	Metal	Metal+Wood	Metal	Metal
	Lighting	Metal+Glass	Metal+Glass	Metal+Glass	Metal+Glass
	Information Boards		Metal+Glass		
WATER FEATURES	*Fountains*	Concrete			
	Ornamental pools			Concrete+Mosaic	
BOUNDARY	*Walls*	Concrete	Concrete	Concrete	
	Fences		Steel	Steel	
	Vegetative boundaries				
PLAYGROUNDS AND SPORTS AREAS	*Playgrounds*	Wood, Rubber Plastic	Wood, Rubber, Plastic	Plastic	Plastic
	Sports fields	Metal+Plastic			Metal+Plastic
PATHWAYS	*Pedestrian paths*	Concrete Bloks Rubber	Concrete Bloks	Concrete Bloks	Concrete Bloks Rubber
	Bicycle lanes	Rubber			Rubber
	Vehicle roads/Parking areas				
OTHER FURNITURE	*Restrooms*		Concrete	Concrete	Prefabricated
	Security booth	Concrete	Concrete	Concrete	
	Sculptures/Art Installations	Metal	Metal		
					COLOR CHARACTERISTIC
URBAN FURNITURE	*Benches*	Black+Brown	Gray+Brown	Brown+ Black/Gray	Gray+Brown
	Gazebos/Pergolas	Brown	Brown		
	Trash bins	Black+Brown	Gray+Brown	Gray+Brown	Gray+Brown
	Lighting	Black Pole+ White LED	Black/Yellow/Blue /Green Pole+ White LED	Black Pole+ White LED	Black Pole+ White LED
	Information Boards			White pano + Gray Pole	
WATER FEATURES	*Fountains*	Dark Gray			
	Ornamental pools			Gray + Blue	
BOUNDARY	*Walls*	Gray	Gray	Gray	
	Fences		Dark green	Dark green	
	Vegetative boundaries				
PLAYGROUNDS AND SPORTS AREAS	*Playgrounds*	Brown, Red, Blue, Yellow	Brown, Red, Blue, Yellow	Red, Blue, Yellow	Red, Blue, Yellow
	Sports fields	Gray+ Yellow+Burgundy			Gray+ Yellow+Burgundy
PATHWAYS	*Pedestrian paths*	Gray+ Burgundy	Gray	Gray	Gray+ Burgundy
	Bicycle lanes	Burgundy			Burgundy
OTHER FURNITURE	*Restrooms*		Gray	Green	Gray
	Security booth	Green	Gray	Green	
	Sculptures/Art Installations	Black+ Blue+Yellow+ Orange	Black+ Blue+Yellow+ Orange		
(gray cell)	There is no equipment to be evaluated in the NPs.				

3.2 Rating the NPs' furniture

Secondly, scores ranging from 0 to 5 were assigned to each criteria to assess the different conditions of the 13 listed criteria in the field. This evaluation, conducted through on-site observations, aimed to determine the positive and negative aspects of the urban furniture in NPs. Initially, the features suitable for urban furniture in NPs were considered based on the characteristics and rating guidelines outlined in Appendix 1. Accordingly, the scores assigned to each urban furniture is presented in Table 4. The key findings identified are as follows:

- **Material:** NP1 and NP2 received the highest scores while NP4 had the lowest regarding material quality and diversity. In NP3, the ornamental pool's glass mosaic coating and the prefabricated toilet in NP4 were deemed partially durable. Rubber-coated pedestrian and bicycle paths and sports areas were ergonomically favorable, whereas NP4's concrete blocks were considered insufficient.
- **Ergonomics:** NP1 received the highest score, whereas NP2, NP3, and NP4 exhibited several shortcomings. These included backs lacking back support, inadequate waste disposal angles in trash bins, the absence of solar-powered lighting, highly reflective information boards in NP3, and poor placement of the fountain in NP1 which obstructed the walking path.
- **Inclusive Design:** NP1 was the most compliant with inclusive design principles while NP4 was the least. Key deficiencies included the absence of wheelchair waiting areas, a lack of tactile surfaces for the visually impaired, and inaccessibility of toilets and security booths.
- **Color:** Urban furniture colors were generally appropriate, but inconsistencies were observed. The white LED lighting in NP3 was suitable, but multicolored lighting poles were only partially suitable. The dark gray fountain in NP1 had a negative impact on the user's perception and comfort.
- **Safety:** Urban furnitures in NP1 and NP2 were moderately well-maintained, NP3 was in good condition while NP4 was neglected. Though the electrical safety infrastructure was adequate, the lack of drainage in NP3 and NP4 was a concern. Some furniture in NP4 was also inadequately secured.
- **Vandalism:** Damages (breakage, graffiti, and unauthorized painting) were observed across parks. NP2 and NP3 showed fewer signs of vandalism because they were newer or recently renovated. In contrast, vandalism was more prevalent in NP1 and NP4.

NP1 and NP2 were the most suitable parks for urban furniture while NP4 was the least suitable. While material suitability was mostly met, deficiencies in ergonomics, Inclusive Design, and safety were noted. Municipalities are advised to renew urban furniture, adopt inclusive design standards, and implement anti-vandalism measures.

3.3 Determination of suitability classes

Finally, the maximum achievable total score for each NPs across all criteria was calculated. The highest possible score was 1270 points, 40 points for ground materials, 95 points for compliance standards, user diversity, and material suitability, and 105 points for other criteria. Based on these calculations, the ergonomic suitability percentages of park furniture and its total scores were assessed to classify their suitability as presented in Table 5.

Table 4. Rating of furniture

			URBAN FURNITURE					WATER		BOUNDARY			PLAY/ SPORTS		PATHWAYS			OTHER			
CRITERIA		NPs ID	Benches	Gazebos/Pergolas	Trash bins	Lightings	Information boards	Fountains	Ornamental pools	Walls	Fences	Vegetative boundaries	Playgrounds	Spor Fields	Pedestrian paths	Bicycle lanes	Parking areas	Restroom	Security booth	Sculptures/Art Installations	TOTAL
Material	Material type	NP1	5	5	5	5		5		5			5	5	5	5			5	5	60
		NP2	5	5	5	5				5	5		5		5			5	5	3	53
		NP3	5		5	5	5		3	5	5		5		5			5	5		53
		NP4	5		5	5							5	5	5	5		3			38
	Material properties	NP1	5	5	5	5		4		3			5	3	4	5			3	4	51
		NP2	4	5	5	5				3	4		5		4			3	3	4	45
		NP3	4		5	5	5		3	3	4		4		3			3	3		42
		NP4	4		5	5							4	4	3	5		4			34
	Surface materials	NP1											5	4	4	5					18
		NP2											5		4						9
		NP3											5		4						9
		NP4											5	5	3	5					18
Ergonomic	Compliance with standards	NP1	5	5	3	3		3		5			5	5	5	5			3		47
		NP2	3	5	3	3				0	0		5		5			3	3		30
		NP3	3		3	3	3			0	0		5		5			3	3		28
		NP4	5		3	3							5	5	5	5		0			31
Inclusive design		NP1	3	3	5	3		3					0	0	3	5			0		25
		NP2	0	5	5	3							0		3			0	0		16
		NP3	0		5	3	5		0				0		3			0	0		16
		NP4	0		5	3							0	0	0	5		0			13
Color		NP1	5	5	5	5		0		5			5	5	5	5			5	3	53
		NP2	5	5	5	3				5	5		5		5			5	5	3	51
		NP3	5		5	5	0		5	5	5		5		5			5	5		50
		NP4	5		5	5							5	5	5	5		5			40
Safety	Maintenance	NP1	3	3	3	3		3		3			3	3	3	3			3	3	36
		NP2	3	3	3	5				5	5		3		3			5	5	5	45
		NP3	5		5	5	3		3	3	5		5		5			5	5		49
		NP4	0		0	0							0	0	0	0		0			0
	Infrastructural stability	NP1	5	5	5	5		5		5			5	5	5	5			5	5	60
		NP2	5	5	5	5				5	5		5		5			5	5	5	55
		NP3	3		3	3	3		3	3	3		3		3			3	3	3	36
		NP4	3		3	3							3	3	3	3		3			24
	Safe design	NP1	5	4	4	5		4		5			5	4	5	5			5	4	55
		NP2	5	4	4	5				5	4		5		5			4	4	5	50
		NP3	5		4	5	3		5	5	4		5		5			4	5		50
		NP4	5		4	5							5	4	5	5		4			37
Vandalism	Breaking and Shattering	NP1	0	0	0	5		0		0			0	5	0	0			5	5	20
		NP2	0	0	0	5				5	5		0		0			5	5	5	30
		NP3	5		5	5	0		0	5	5		5		0			5	5		40
		NP4	0		0	5							0	0	0	0		5			10
	Cutting, Scratching, and Carving	NP1	0	0	0	5		5		0			0	0	5	0			5	5	25
		NP2	5	0	5	5				5	5		0		5			5	5	5	45
		NP3	5		5	5	0		5	0	5		5		5			5	5		45
		NP4	0		5	5							0	5	0	0		5			20
	Burn	NP1	5	5	0	5		0		5			5	5	5	5			5	5	50
		NP2	5	5	5	5				5	5		5		5			5	5	5	55
		NP3	5		5	5	5		5	5	5		5		5			5	5		55
		NP4	5		5	5							0	5	5	5		5			35
	Graffiti and Paint	NP1	0	0	5	5		0		0			5	0	5	5			5	5	35
		NP2	5	0	5	5				5	5		5		5			5	5	5	50
		NP3	5		5	5	5		5	5	5		5		5			5	5		55
		NP4	5		0	5							5	5	5	5		5			35

(Grey) There is no equipment to be evaluated in the NPs. (Orange) The criteria were not considered in the evaluation of the relevant furniture.

Table 5. Determination of suitability classes based on furniture in NPs

Main Criteria	Sub-criteria \ NPs	Yenişehir Municipality Park (NP1)		Child's Life Park (NP2)		Aziz Sancar Park (NP3)		Ebu Ali el Cezeri Park (NP4)	
		∑	%	∑	%	∑	%	∑	%
Materials	Material type	60	57.1	53	50.5	53	50.5	38	36.2
	Material properties	51	48.6	45	42.9	42	40.0	34	32.4
	Surface materials	18	45.0	9	22.5	9	22.5	18	45.0
Ergonomic	Compliance with standards	47	49.5	30	31.6	28	29.5	31	32.6
Inclusive design		14	26.3	16	16.8	16	16.8	13	38.1
Color		57	55.8	51	53.7	50	52.6	40	42.1
Safety	Maintenance	36	34.3	45	42.9	49	46.7	0	0.0
	Infrastructural stability	60	57.1	55	52.4	36	34.3	24	22.9
	Safe design	55	52.4	50	47.6	50	47.6	37	35.2
Vandalism	Breaking and Shattering	20	19.0	30	28.6	40	38.1	10	9.5
	Cutting, Scratching, and Carving	25	23.8	45	42.9	45	42.9	20	19.0
	Burn	50	4.6	55	52.4	55	52.4	35	33.3
	Graffiti and Paint	35	33.3	50	47.6	55	52.4	35	33.3
Suitability score and percentage		**535**	**42.1**	**534**	**42.0**	**528**	**41.6**	**335**	**26.4**
Suitability class		Moderate Suitable		Moderate Suitable		Moderate Suitable		Less Suitable	

- **Material:** NP1 received the highest score (57.1%) while NP4 had the lowest (36.2%). Regarding material properties, NP1 was the most suitable park, whereas NP4 had the lowest rating with a 32.4% suitability score. For surface materials, NP1 and NP4 scored the highest at 45.0% while NP2 and NP3 had a lower suitability percentage of 22.5%.
- **Ergonomics:** NP1 had the highest compliance rate with standards at 49.5% while NP3 and NP4 received lower scores at 29.5% and 32.6%, respectively. In terms of user diversity, NP1 scored highest at 26.3%, whereas NP4 recorded the lowest score at 38.1%.
- **User Diversity:** NP1 had the highest suitability rate at 26.3% while NP4 had the lowest at 38.1%. NP2 and NP3 both scored 16.8%. These findings suggest NPs do not fully adhere to inclusive design principles and demonstrate shortcomings in supporting user diversity.
- **Color:** NP1 had the highest suitability level (55.8%) while NP4 had the lowest (42.1%). This suggests that color coordination varied across the parks.
- **Safety:** Regarding maintenance, NP3 had the highest compliance level (46.7%), whereas NP4 scored the lowest (0%). For secure anchoring and infrastructure, NP1 scored the highest (57.1%) while NP4 had the lowest (22.9%). In terms of appropriate design, NP1 (52.4%) and NP2 (47.6%) scored the highest while NP4 scored the lowest (35.2%).
- **Vandalism:** NP3 was the most affected park by breakage and destruction (38.1%) while NP4 had the lowest impact (9.5%). NP2 and NP3 (42.9%) were the most affected by cutting, scratching, and graffiti, whereas NP4 had the lowest score (19.0%). Fire-related vandalism was more common in NP2 and NP3 (52.4%) and less in NP4 (33.3%). Paint-related vandalism was most frequent in NP3 (52.4%) while NP1 and NP4 had lower rates (33.3%).

Considering the overall suitability scores and percentages, NP1 (42.1%), NP2 (42.0%), and NP3 (41.6%) were classified as moderately suitable. NP4 was categorized as less suitable with a suitability rate of 26.4%. Based on these evaluations, NP1 and NP2 were identified as the most appropriate parks in terms of furniture while NP4 required improvements and furniture enhancements. Addressing ergonomics, safety, and user diversity deficiencies is crucial for making NPs more functional and user-friendly.

4 Discussion and Conclusion

This study evaluated the NPs in the Fabrika Neighborhood of Yenişehir District, Diyarbakır, Türkiye, in terms of urban furniture criteria: material quality, ergonomics, user diversity, color coordination, safety, and resistance to vandalism. The findings revealed a generally moderate level of suitability across the parks, but also identified several critical deficiencies requiring attention.

- Material: Durability, sustainability, and safety are essential for effective park design (Sipahi and Sipahi, 2024; Grabiec et al., 2022). Concrete, though common, poses environmental concerns due to its non-recyclable nature, highlighting a shift toward more eco-friendly alternatives. Preferred materials such as wood, recyclable metals, and composites offer improved longevity and ecological performance (Aksu, 2015). For water features, epoxy-based waterproof coatings and specialized ceramics are recommended over fragile glass mosaics. Playgrounds should prioritize sustainable and safe materials for children (Bhaskaran et al., 2024) replacing plastic elements with wood or recyclable composites. Similarly, toilets should integrate natural materials such as wood, stone-textured panels, and green roofs for aesthetic harmony. Balancing cost, user safety, and sustainability ensures eco-friendly, functional, and visually cohesive park environments.
- Ergonomic: Ensuring that park furniture aligns with ergonomic principles enhances user-friendliness and accessibility (Appolloni et al., 2020; Gamito and Sousa, 2019). Benches should include backrests and armrests to improve comfort while their strategic arrangement and designated waiting areas for individuals with disabilities enhance accessibility. Trash bins should feature a 45–60° inclined opening for easier use and be positioned in high-traffic areas. Information boards must be made from non-reflective materials to improve readability under sunlight while including park maps, emergency contacts, and directional signs will enhance the user experience. Drinking fountains should be easily accessible and unobstructive to pedestrian pathways. Additionally, they should meet height standards suitable for individuals with disabilities and children. These improvements will encourage park usage, promote inclusivity, and enhance overall functionality, ensuring that parks cater to the diverse needs of all visitors.
- Accessibility and user diversity: Ensuring accessibility for individuals of all ages and abilities is fundamental to inclusive park design (Kesik et al., 2014; Lee, 2021). Assessments of NPs have identified several shortcomings in providing equal access for individuals with disabilities. Therefore, key modifications must be implemented to enhance accessibility. Benches and gazebos should be systematically arranged to ensure equitable park use, and designated waiting areas for wheelchair users should be established. Additionally, integrating tactile paving on pedestrian pathways will enable visually impaired individuals to navigate the park more comfortably. Restroom facilities often fail to meet accessibility standards as their dimensions are inadequate. Restrooms should be expanded to a minimum size of 2.25 x 2.25 meters to comply with accessibility regulations. These improvements will promote inclusivity and ensure that all users can enjoy public parks safely and comfortably.

- Safety and Vandalism: Maintenance conditions revealed that NP1 and NP2 were partially maintained while NP3 and NP4 exhibited maintenance deficiencies. Addressing these issues is crucial for ensuring the longevity of parks and enhancing user comfort (Douglas et al., 2018). Vandalism remains one of the most significant challenges faced by NPs. Studies indicate that the most common forms of vandalism in park areas are destruction and graffiti (Marquet et al., 2019). These issues negatively impact the aesthetic value and usability of parks. Awareness campaigns should be organized to mitigate vandalism, and damaged furniture should be promptly repaired (Echeverría et al., 2014). Additionally, park lighting should be optimized to improve nighttime security, and durable, vandal-resistant materials must be used. Maintenance deficiencies in NP3 and NP4 should be resolved through regular upkeep efforts.
- Emergency Response Capabilities: The lack of vehicle access roads in national parks significantly impedes emergency response efforts. Situations requiring urgent medical or security interventions are at substantial risk due to the absence of designated access routes at park entrances (Sohn et al., 2015). Therefore, park designs must incorporate pathways that enable emergency vehicles to enter efficiently.
- Designing parks with a sustainable and user-friendly approach is essential for enhancing urban quality of life. Municipalities should address the identified deficiencies by upgrading urban furniture, ensuring equitable distribution, and applying universal design principles. These improvements will foster the development of more functional, accessible, and welcoming NPs. Moreover, this study underlines the importance of integrating quantitative and qualitative data in future research. While this study primarily focused on quantitative analysis, incorporating qualitative insights will provide more comprehensive guidance for urban planners and policymakers. This integration will support the development of resilient, user-friendly, and sustainable green spaces that meet the evolving needs of urban populations.

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Authors' contribution
Kübra Aktaş Akın: Conceptualization (development of the research idea and objectives), Methodology design, Investigation. **Müge Ünal:** Conceptualization, Data analysis, Data curation, Resources, Supervision, Validation, Visualization, Draft preparation, Writing – the original draft, Reviewing and editing.

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Appendix 1. The characteristics of the evolution criteria and rating scores

	THE CHARACTERISTICS OF EVALUATION CRITERIA	SCORE
MATERIALS	**MATERIAL TYPE:** The material type was examined on-site and evaluated based on its suitability for the intended use, with scoring assigned according to the presence of appropriate materials. • **Benches and Gazebos:** While wood and natural stone are preferred as primary materials, combinations of concrete and metal can also be incorporated into the design. • **Trash Bins:** Metal, wood, fiberglass, and cast concrete • **Lighting:** Stainless steel, aluminum, wood, and cast iron • **Signage:** UV-resistant metal, wood, and plexiglass are preferred materials. • **Fountains:** Stainless steel, cast stone, natural stone, and concrete • **Pools:** Natural stone, marble, stainless steel, fiberglass, and concrete. Stone or metal mosaic can be added. • **Walls and Fences:** Recommended materials include natural stone, concrete, brick, metal (such as wrought iron), and wood. Innovative materials like polymer-coated metal or bamboo can also be used for fencing. • **Playgrounds and Equipment:** Wood, plastic, metal, rubber coatings, and soft flooring materials such as rubber tiles or artificial turf • **Sports Areas:** Suitable flooring materials include Rubber, acrylic coatings, and concrete. Durable stainless steel and PVC coatings are recommended for sports equipment. • **Pedestrian and Bicycle Paths:** Concrete, asphalt, interlocking paving stones, and eco-friendly permeable coatings are suitable. Bicycle paths should have non-slip surfaces to ensure safety. • **Vehicle Roads:** Asphalt, concrete, or interlocking paving stones • **Restrooms:** Stainless steel, fiberglass, and concrete are recommended materials, with ceramic coatings for interior surfaces • **Sculptures:** Marble, stone, bronze, stainless steel, wood, and, for modern designs, fiberglass and polymer materials with UV-resistant coatings for outdoor durability.	Not suitable: 0 Partially suitable: 3 Suitable: 5
	MATERIAL PROPERTIES: Material properties are crucial in ensuring a design's functionality, safety, and aesthetics. The selection of appropriate materials was based on the following key criteria: • **Durability and Longevity:** The material should resist wear, breakage, and environmental conditions (e.g., rain, snow, and sunlight). • **Ease of Cleaning:** Maintenance and cleaning should be straightforward, particularly in public spaces where hygiene is essential. • **Temperature and Climate Resistance:** The material must withstand sudden temperature changes and diverse climatic conditions (e.g., preventing wood decay or metal corrosion). • **Natural and Aesthetic Compatibility:** The material should harmonize with the surrounding environment and provide a natural appearance (e.g., wood and stone). • **Eco-Friendly and Recyclable:** Environmentally sustainable and recyclable materials should be prioritized to minimize environmental impact.	Not suitable: 0 1 feature present: 1 2 features present: 2 3 features present: 3 4 features present: 4 5 or more features present: 5
	SURFACE MATERIALS: The assessment of this criteria was based on the suitability of the following material properties: 1. **Pedestrian-Friendly Surfaces:** The surface should not hinder pedestrian movement, avoiding excessive roughness, depressions, or bumps. 2. **Appropriate Joint Spacing and Width:** Ensuring pedestrian safety and comfort through proper joint placement. 3. **Surface Reflectivity:** Consider the albedo value to enhance energy efficiency and user comfort. 4. **Non-Slip Properties in Wet Conditions:** Surfaces should not become slippery during rainfall. 5. **Sufficient Road Infrastructure:** Durable sublayers, such as compacted soil, stabilized fill, or blocking layers, should support surface materials. This evaluation was applied to the **ground materials used in playgrounds, sports fields, recreational areas, and pathways**, ensuring functionality, safety, and durability.	Not suitable: 0 1 feature present: 1 2 features present: 2 3 features present: 3 4 features present: 4 5 or more features present: 5
INCLUSIVE DESIGN	**INCLUSIVE DESIGN:** Inclusive Design was assessed based on the following criteria: • Sensory Accessibility: Structural and vegetative designs should integrate color, texture, scent, and sound stimuli to enhance perception, especially for individuals with disabilities. • Placement of Elements: Lighting, signs, hanging plants, and trees should be positioned within a 75-120 cm strip, while tree branches should begin at least 220 cm to prevent obstructions. • Seating Areas: Benches should be placed at 100-200 m intervals for accessibility. The seating height should be 45 cm, with a 70 cm backrest, and wheelchair spaces should be allocated next to seating areas. • Trash Bins: Positioned at least 40 cm from the curb, installed at a 90-120 cm height, and made of non-hazardous materials to prevent injuries. • Rest Area Tables: Table height should be 75-90 cm, with a 60 cm minimum clearance underneath for wheelchair access. • Fountains: Installed at a height of 85 cm for wheelchair accessibility. • Tree Planting & Vegetation: Trees should be planted within a 75-120 cm strip. Vegetation near ramps and staircases should not shed fruit or create slippery surfaces. • Pedestrian Walkways should have a minimum width of 1.5 meters. • Restrooms (WC): Must be at least 2.25 x 2.25 meters for accessibility.	Not suitable: 0 Partially suitable: 3 Suitable: 5
VANDALIS M	**VANDALISM:** Vandalism, defined as the intentional damage to an object valued by individuals or the public, through breaking, destroying, cutting, burning, or defacing with paint, leads to a decline in the visual quality of the area. It also threatens users' physical and psychological well-being (Şahin et al,, 2019; Kara et al., 2024). The types of vandalism in equipment elements will be identified and evaluated in the study area through a scoring system.	Present: 0 Absent: 5

	THE CHARACTERISTICS OF EVALUATION CRITERIA	SCORE
ERGONOMIC	**COMPLIANCE WITH STANDARDS:** Public furniture and structures were assessed based on ergonomic characteristics and relevant standards from the literature. • **Benches:** a) Seat height/depth: 40-45 cm / 45-50 cm; b) Backrest: 45-50 cm height; 10-15° tilt; c) Armrest Dimensions: Width: 5-7 cm, Height: 20-25 cm; d) Weight capacity: Minimum 250 kg; e) Seat inclination: 3-5° • **Trash Bins:** a) Height: 90-110 cm; b) Opening/closing mechanism: Pedal-operated or manual for easy use; c) Capacity: 30-50 liters (individual use); 60-100 liters (public use); d) Stability: Securely fixed to the ground; e) Waste disposal angle: 45-60° • **Lighting:** a) Height: 3-5 m (for pedestrians), 8-12 m (for roadways); b) Suitability for nighttime use; c) Glare and reflection prevention; d) Energy efficiency: LED or solar-powered systems • **Signage and Information Panels:** a) Height: 1.2-1.5 m (for pedestrians); b) Visual accessibility & readability; c) Illumination for night visibility • **Drinking Fountains:** a) Height: 85-95 cm (75 cm for accessible areas); b) Minimum open space around unit: 1.5 x 1.5 m • **Boundary Elements:** a) Height: 50-70 cm (low barriers), 100-120 cm (high barriers); b) Metal fence spacing: 10-12 cm between bars • **Playgrounds:** a) Age-appropriate equipment selection: Proper slide slope, width, step spacing, swing height, chain length, seat width, seesaw length, and height; b) Diversity of play equipment: At least three different elements for varying age groups; c) Suitable vegetation for shade and aesthetics; d) Safe and controlled location • **Pathways & Pedestrian Areas:** a) Pedestrian traffic density: >6 m^2 per person (very spacious), 6-4 m^2 per person (comfortable), 4-2.5 m^2 per person (moderate), 2.5-1.5 m^2 per person (crowded), <0.75 m^2 per person (overcrowded); b) Physical accessibility: Sidewalks and ramps must meet accessibility standards (maximum 8% slope**)** (Unal and Uslu, 2018) • **Sports Areas:** a) Orientation: North-South alignment for optimal sun exposure control **Other furniture** must be of adequate quantity and quality within the designated space.	Not suitable: 0 Partially suitable: 3 Suitable: 5
COLOR	**COLOR:** It is a crucial element in industrial product design, strengthening the connection between the product and the user while enhancing functionality and aesthetics. Although often seen as secondary to form, color completes the design and directly impacts usability, durability, and visual harmony. Appropriate colors for different urban furniture elements ensure a cohesive, attractive, and functional environment. • **Benches and Gazebos:** For wood and natural stone elements, use neutral, natural tones such as light brown, walnut, and gray stone. Pastel or matte shades like dark green, anthracite, and beige create visual cohesion for concrete and metal combinations. • **Trash Bins:** Metal bins should be black, dark green, or gray to complement natural materials, while fiberglass bins should use bright, durable colors like blue or green for visibility. • **Lighting Elements:** Lamp posts should be finished in black, anthracite gray, or dark bronze for a classic and resilient appearance. Warm white or natural LED lighting minimizes eye strain and improves comfort. • **Drinking Fountains and Pools:** Stone or ceramic finishes in white, light blue, or beige convey cleanliness and freshness, while metal components should use stainless steel gray or matte black. • **Walls and Fences:** Natural stone tones like beige and gray should be preserved for stone walls, and metal fences should be finished in matte black or dark gray to ensure durability and aesthetic balance. • **Pedestrian paths** should feature light gray or beige for better heat reflection and aesthetic integration. • **Bicycle Paths:** should use red or green for increased visibility and safety. • **Vehicle Roads:** Traditional dark gray asphalt or light-colored concrete • **Restrooms:** Exterior colors like light gray, white, or dark green are easy to clean and maintain. • **Sculptures:** Natural materials such as bronze or marble should retain their original color. Modern concrete sculptures with metallic tones (gray, black) or contrasting colors may stand out. • **Children's Play Equipment:** Wooden structures should maintain natural wood tones, while plastic elements should feature bright, engaging colors like red, blue, green, and yellow. Ground surfaces should use soft natural tones like green, beige, or light gray for comfort. • **Sports Fields:** Court flooring should contrast with white boundary lines to improve visibility, such as red flooring with white lines for safety and clarity.	Not suitable: 0 Partially suitable: 3 Suitable: 5
SAFETY	**MAINTENANCE:** The equipment elements were scored based on their maintenance condition	Neglected: 0 Partially: 3 Well-maintained: 5
	INFRASTRUCTURAL STABILITY: Equipment should have appropriate anchoring and infrastructure features. To prevent displacement or tipping, furniture and flooring materials must be tamper-resistant and stable. The electrical connections of lighting elements are a critical safety consideration. Additionally, proper drainage must be ensured for water-related installations and throughout the entire equipment area.	Not suitable: 0 points Partially suitable: 3 points Suitable: 5 points
	SAFE DESIGN: The evaluation of this criteria considers the presence of the following features: 1. **Appropriate Spatial Features** 2. **Prevention of Sharp Edges:** All elements must be free of sharp edges to ensure safety. Rounded edges should be used, especially in children's play equipment. 3. **Non-Slip Surfaces:** Non-slip surfaces are essential for pedestrian paths, bicycle lanes, and sports fields 4. **Weather Resistance:** Materials should be durable against rain, wind, and temperature fluctuations. 5. **Ease of Maintenance and Cleaning:** All elements should be made of materials that are easy to clean and require minimal maintenance. 6. **Accessible Design for Individuals with Disabilities:** Restrooms, pedestrian paths, and signage should be accessible to everyone.	Not suitable: 0 1 feature present: 1 2 features present: 2 3 features present: 3 4 features present: 4 5 or more features present: 5

Mobilya ve Ahşap Malzeme Araştırmaları Dergisi
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Optimization of facility layout design in furniture manufacturing using fuzzy AHP and fuzzy EDAS and comparison with fuzzy ARAS

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ABSTRACT: Efficient facility layout design is crucial for optimizing operations, reducing costs, and enhancing productivity in manufacturing environments. This study focuses on evaluating and prioritizing layout alternatives for a furniture manufacturing facility in Türkiye. An integrated decision-making methodology combining fuzzy AHP (analytic hierarchy process) and fuzzy EDAS (evaluation based on distance from average solution) is employed to solve the problem. The fuzzy AHP procedure is applied to assess the importance of criteria influencing facility layout decisions. The fuzzy EDAS procedure is used to evaluate and rank facility layout alternatives. To support the model results, a comparative analysis using fuzzy ARAS and a sensitivity analysis based on weight variations are conducted. Flexibility emerges as the most important criterion with a weight of 35.56%. Among the alternatives, layout option A3 demonstrates the best performance with a score of 0.9872, corresponding to a 68.28% share. The study results demonstrate significant operational improvements, including reduced production distances, enhanced energy efficiency, minimized bottlenecks, and accelerated assembly processes. This research serves as a valuable reference for addressing similar optimization challenges across various industries.

Keywords: Furniture facility design, AHP, EDAS, ARAS, Fuzzy set

Mobilya üretiminde bulanık AHP ve bulanık EDAS kullanılarak tesis yerleşim tasarımının optimizasyonu ve bulanık ARAS ile karşılaştırma

ÖZ: Üretim ortamlarında operasyonların optimize edilmesi, maliyetlerin azaltılması ve verimliliğin artırılması açısından etkili bir tesis yerleşim tasarımı büyük önem taşır. Bu çalışma, Türkiye'deki bir mobilya üretim tesisine yönelik yerleşim alternatiflerini değerlendirmeye ve önceliklendirmeye odaklanmaktadır. Problemin çözümünde, bulanık AHP (analitik hiyerarşi süreci) ve bulanık EDAS (ortalama çözüme uzaklığa dayalı değerlendirme) yöntemlerini birleştiren entegre bir karar verme metodolojisi kullanılmaktadır. Bulanık AHP yöntemi, tesis yerleşim kararlarını etkileyen kriterlerin önem derecesini değerlendirmek için uygulanmaktadır. Bulanık EDAS yöntemi ise tesis yerleşim alternatiflerini değerlendirmek ve sıralamak amacıyla kullanılmaktadır. Model sonuçlarını desteklemek amacıyla, bulanık ARAS kullanılarak bir karşılaştırmalı analiz ve ağırlık değişimlerine dayalı bir duyarlılık analizi gerçekleştirilmektedir. Esneklik %35,56 ağırlık ile en önemli kriter olarak öne çıkmaktadır. Alternatifler arasında, A3 yerleşim seçeneği 0,9872 puanla en iyi performansı sergilemekte olup, bu değer %68,28'lik bir paya karşılık gelmektedir. Çalışma sonuçları; üretim mesafelerinin azaltılması, enerji verimliliğinin artırılması, darboğazların en aza indirilmesi ve montaj süreçlerinin hızlandırılması gibi önemli operasyonel iyileşmeleri ortaya koymaktadır. Bu araştırma, çeşitli endüstrilerde benzer optimizasyon sorunlarının ele alınmasında değerli bir kaynak niteliği taşımaktadır.

Anahtar kelimeler: Mobilya tesisi tasarımı, AHP, EDAS, ARAS, Bulanık küme

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1 Introduction

Facility layout planning plays a crucial role in the design and optimization of manufacturing systems, service organizations, and logistics operations. It is a strategic endeavor aimed at arranging physical resources, including equipment, workstations, and storage areas, within a facility to maximize efficiency, safety, and operational effectiveness (Besbes et al., 2020). Facility layout planning directly influences productivity, costs, material flow, energy consumption, and overall organizational performance. A well-designed layout minimizes transportation and handling costs, improves communication and workflow, and supports scalability and adaptability in dynamic environments (Zha et al., 2020).

Facility layout planning has been approached through various methodologies, including systematic layout planning, mathematical optimization, and heuristic techniques. Traditionally, the focus has been on single-objective optimization, often prioritizing cost or space utilization (Al-Zubaidi et al., 2021). However, modern industries operate in complex and competitive environments, where decision-making involves balancing multiple, and sometimes conflicting, criteria. This shift has highlighted the need for multicriteria decision-making (MCDM) approaches in facility layout planning. A structured and systematic approach that integrates multiple criteria into the decision-making process is essential for effective facility layout planning (Nenzhelele et al., 2023).

MCDM is a branch of operations research that focuses on evaluating a set of alternatives based on a predefined set of criteria. These criteria can be either quantitative or qualitative, depending on the context of the decision-making problem. MCDM involves analyzing and comparing various options to assist decision-makers in selecting the most appropriate solution. The key components of MCDM include goals, alternatives, criteria, weights, and decision-makers' preferences (Mofarrah, 2008; Kumar et al., 2017). MCDM encompasses a variety of methods aimed at aiding decision-makers in scenarios where multiple decision elements must be considered simultaneously. Some of the most popular MCDM methods include the analytic hierarchy process (AHP), the technique for order of preference by similarity to ideal solution, the weighted aggregated sum product assessment, the evaluation based on distance from average solution (EDAS), and the decision-making trial and evaluation laboratory.

Traditional MCDM methods utilize crisp numerical inputs, which may not adequately represent real-world conditions. Fuzzy logic provides a framework for incorporating human-like reasoning into MCDM. Fuzzy set theory allows elements to have partial membership in a set, represented by membership functions ranging from 0 to 1. This capability makes fuzzy MCDM well-suited for problems involving human judgment. Fuzzy MCDM is an advanced decision-support technique that integrates the principles of fuzzy set theory into multicriteria decision analysis (Keshavarz Ghorabaee et al., 2018). In a typical fuzzy MCDM process, decision-makers first define decision elements. The ratings for criteria and alternatives are expressed using linguistic terms and fuzzy numbers (connected set of possible values). Fuzzy MCDM is particularly useful in situations where decision-making involves multiple, often conflicting criteria, and where the input data or preferences are imprecise, uncertain, or subjective (Petrović et al., 2019).

An integrated fuzzy decision-making methodology, consisting of AHP and EDAS, is employed in this study for modeling and analyzing the facility layout problem. AHP solves complex problems by structuring them into a hierarchical framework. By using pairwise comparisons and a numerical scale to assess the importance of decision elements, AHP assigns priority weights to criteria and ranks alternatives (Özşahin et al., 2019; Kuşcuoğlu and

Dilik, 2023). AHP offers numerous advantages, making it a valuable tool for decision-making. One of its key strengths is its ability to structure complex problems into a clear hierarchy, enabling systematic analysis of each component. AHP includes a consistency check to ensure that pairwise comparisons are reliable. Its emphasis on both qualitative and quantitative factors enhances the overall quality and defensibility of decisions (Moeinaddini et al., 2010). In this study, fuzzy AHP is used to prioritize facility layout selection criteria. EDAS is designed to rank alternatives based on their proximity to an ideal solution. This method calculates positive and negative distances for each criterion, aggregates them, and uses these values to determine the overall performance score of each alternative (Keshavarz Ghorabaee et al., 2015). EDAS offers several advantages. One of its primary strengths is its ability to balance positive and negative deviations from the average solution. This dual consideration minimizes bias and ensures that all aspects of performance are considered. Additionally, EDAS is computationally straightforward, making it accessible and easy to implement across various decision-making scenarios. Its reliance on the average solution as a reference point makes it particularly suitable for situations where extreme values or outliers might distort the results of other MCDM methods (Torkayesh et al., 2023). In this study, fuzzy EDAS is used to prioritize facility layout alternatives.

The purpose of this study is to evaluate and prioritize facility layout alternatives for a furniture manufacturing facility by integrating the AHP and EDAS methods within a fuzzy environment. The motivation stems from the significant impact of facility layout decisions on operational efficiency and resource optimization in furniture manufacturing. The fuzzy AHP procedure is used to determine the importance of criteria influencing facility layout decisions, while the fuzzy EDAS procedure is applied to rank facility layout alternatives. This study provides a reliable and flexible tool to support strategic facility layout decisions.

2 Materials and Methods

2.1 Fuzzy sets and fuzzy numbers

Fuzzy set theory extends the classical concept of sets by allowing elements to have partial membership rather than a binary inclusion or exclusion. In classical set theory, an element either belongs to a set (membership value of 1) or does not belong (membership value of 0). However, in many real-world scenarios, boundaries between categories or sets are not clear-cut, leading to uncertainty and vagueness. Fuzzy sets provide a mathematical framework to handle this imprecision by assigning a membership grade to each element in the range [0, 1]. The degree of membership reflects the extent to which an element belongs to the fuzzy set. A triangular fuzzy number is defined by three parameters (l, m, u), where l is the lower limit, m is the middle value, and u is the upper limit. The membership function of a triangular fuzzy number is defined using Equation (1). The triangular fuzzy number is graphically represented as a triangle on a two-dimensional plane, where the base spans from l to u and the peak occurs at m with a membership value of 1. This simple structure makes it a popular choice in fuzzy modeling (Akdag et al., 2014).

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0, & x < l \text{ or } x > u \\ (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \end{cases} \tag{1}$$

If $\widetilde{M}_1 = (l_1, m_1, u_1)$ and $\widetilde{M}_2 = (l_2, m_2, u_2)$ represent two triangular fuzzy numbers, their common mathematical operations are defined as follows:

$$\widetilde{M}_1 \oplus \widetilde{M}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

$$\widetilde{M}_1 \ominus \widetilde{M}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{3}$$

$$\widetilde{M}_1 \otimes \widetilde{M}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (4)$$

$$\alpha \widetilde{M}_1 = (\alpha l_1, \alpha m_1, \alpha u_1) \quad (5)$$

$$\widetilde{M}_1^{-1} = (1/u_1, 1/m_1, 1/l_1) \quad (6)$$

2.2 Fuzzy AHP method

AHP is designed to address complex MCDM problems by organizing them into a hierarchical structure. The core concept of AHP involves breaking down a problem into a hierarchy of levels, typically starting with the goal at the top, followed by criteria and subcriteria in the middle, and alternatives at the bottom. Decision-makers perform pairwise comparisons of decision elements at each level using a scale of importance ranging from 1 (equal importance) to 9 (extreme importance). AHP incorporates a built-in consistency ratio that evaluates the coherence of pairwise comparisons. Pairwise comparison matrices are constructed and analyzed to obtain weights. These weights reflect the importance of each decision element (Darko et al., 2019). Traditional AHP relies on precise numerical values for pairwise comparisons, but in many real-world scenarios, decision-makers may find it difficult to express their judgments with exact numbers due to the complexity of the problem. Fuzzy AHP addresses this limitation by using fuzzy logic to model these judgments. Some notable studies that have utilized the fuzzy AHP method can be listed as follows: conveyor selection (Nguyen et al., 2016), flood vulnerability assessment (Duan et al., 2022), nuclear power plant selection (Abdullah et al., 2023), third-party logistics provider selection (Wang et al., 2024), and prioritization of renewable energy sources (Luhaniwal et al., 2025). The current study uses the Buckley AHP method to prioritize facility layout selection criteria. This method consists of the following steps (Buckley, 1985; Budak and Ustundag, 2015):

Step 1: A fuzzy pairwise comparison matrix is created according to Equation (7).

$$D = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} \quad (7)$$

where n refers to the number of criteria, and $\tilde{a}_{ij}$ is a triangular fuzzy number representing the importance between two criteria.

Step 2: Geometric means of fuzzy comparison values are calculated using Equation (8).

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \otimes \tilde{a}_{in})^{1/n} \quad (8)$$

Step 3: Fuzzy weight values are calculated using Equation (9).

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} \quad (9)$$

Step 4: Weight vectors are obtained using Equation (10).

$$w_{Fj} = \frac{\widetilde{w}_{Fj}^{'}}{\sum_{j=1}^{n} \widetilde{w}_{Fj}^{'}} = \frac{w_{Fjl} + w_{Fjm} + w_{Fju}}{\sum_{j=1}^{n} \widetilde{w}_{Fij}^{'}} \quad (10)$$

2.3 Fuzzy EDAS method

EDAS serves as an effective tool for assessing and ranking alternatives based on their performance relative to a set of criteria. The central idea of EDAS revolves around the comparison of each alternative with an average solution, which is derived by calculating the mean value of each criterion across all alternatives. For each alternative, two measures are computed: the positive distance from average (PDA) and the negative distance from average (NDA). The final performance score of each alternative is computed by integrating the weighted PDA and NDA values (Keshavarz Ghorabaee et al., 2015). Fuzzy EDAS is a powerful extension of classical EDAS. It is designed to address the challenges of uncertainty and vagueness in decision-making. Fuzzy EDAS is particularly suitable for scenarios where precise data are challenging to obtain. The following are some prominent studies that have employed the fuzzy EDAS method: hospital site selection (Yilmaz and Atan, 2021), energy consumption planning (Demirtas et al., 2021), material selection (Singer and Över Özçelik, 2022), strategy analysis (Le and Nhieu, 2022), and wind turbine selection (Tüysüz and Kahraman, 2023). The current study uses the fuzzy EDAS method to prioritize facility layout alternatives. The steps of this method are as follows (Ghorabaee et al., 2016; Hasheminasab et al., 2019):

Step 1: A decision matrix is structured with m alternatives and n criteria. This matrix contains the performance values ($\tilde{x}_{ij}$) of each alternative across various criteria.

$$A = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}; i = 1,\ldots,m; j = 1,\ldots,n \tag{11}$$

Step 2: Average solutions are obtained using Equation (12).

$$\widetilde{av}_j = \frac{1}{m} \bigoplus_{i=1}^{m} \tilde{x}_{ij} \tag{12}$$

Step 3: PDA and NDA matrices are constructed according to the following equations:

$$\widetilde{pda}_{ij} = \begin{cases} \dfrac{\psi\left(\tilde{x}_{ij} \ominus \widetilde{av}_j\right)}{\kappa(\widetilde{av}_j)} & \text{if } j \in \text{set of benefit criteria} \\ \dfrac{\psi\left(\widetilde{av}_j \ominus \tilde{x}_{ij}\right)}{\kappa(\widetilde{av}_j)} & \text{if } j \in \text{set of cost criteria} \end{cases} \tag{13}$$

$$\widetilde{nda}_{ij} = \begin{cases} \dfrac{\psi\left(\widetilde{av}_j \ominus \tilde{x}_{ij}\right)}{\kappa(\widetilde{av}_j)} & \text{if } j \in \text{set of benefit criteria} \\ \dfrac{\psi\left(\tilde{x}_{ij} \ominus \widetilde{av}_j\right)}{\kappa(\widetilde{av}_j)} & \text{if } j \in \text{set of cost criteria} \end{cases} \tag{14}$$

The function $\kappa(\tilde{A})$ is used to obtain the defuzzified value of a triangular fuzzy number, while the function $\psi(\tilde{A})$ identifies the maximum value between the triangular fuzzy number and zero. Equations (15) and (16) are used to calculate these functions.

$$\kappa(\tilde{A}) = \frac{l + 2m + u}{4} \tag{15}$$

$$\psi(\tilde{A}) = \begin{cases} \tilde{A} & \text{if } \kappa(\tilde{A}) > 0 \\ 0 & \text{if } \kappa(\tilde{A}) \leq 0 \end{cases} \tag{16}$$

Step 4: The weighted sum of PDA and weighted sum of NDA are calculated using Equations (17) and (18).

$$\widetilde{sp}_i = \bigoplus_{j=1}^{n} (\tilde{w}_j \otimes \widetilde{pda}_{ij}) \tag{17}$$

$$\widetilde{sn}_i = \bigoplus_{j=1}^{n} (\widetilde{w}_j \otimes \widetilde{nda}_{ij}) \tag{18}$$

Step 5: The summed values are normalized using Equations (19) and (20).

$$\widetilde{nsp}_i = \frac{\widetilde{sp}_i}{\max_i(\kappa(\widetilde{sp}_i))} \tag{19}$$

$$\widetilde{nsn}_i = 1 - \frac{\widetilde{sn}_i}{\max_i(\kappa(\widetilde{sn}_i))} \tag{20}$$

Step 6: Fuzzy performance scores are obtained using Equation (21).

$$\widetilde{as}_i = \frac{\widetilde{nsp}_i \oplus \widetilde{nsn}_i}{2} \tag{21}$$

Step 7: Crisp performance scores are revealed using Equation (15).

3 Application

3.1 Problem definition

This study focuses on identifying and addressing inefficiencies in the production processes of child bed components within a furniture manufacturing facility in Türkiye. An integrated fuzzy AHP-EDAS methodology is proposed to handle the problem. The current operations face significant challenges that adversely impact operational efficiency, productivity, and customer satisfaction. These issues primarily stem from suboptimal facility layout and production flow, highlighting an urgent need for waste reduction and process optimization. Specifically, the study examines the MOBAKS line within the facility. Figure 1 illustrates the existing operations on the MOBAKS line.

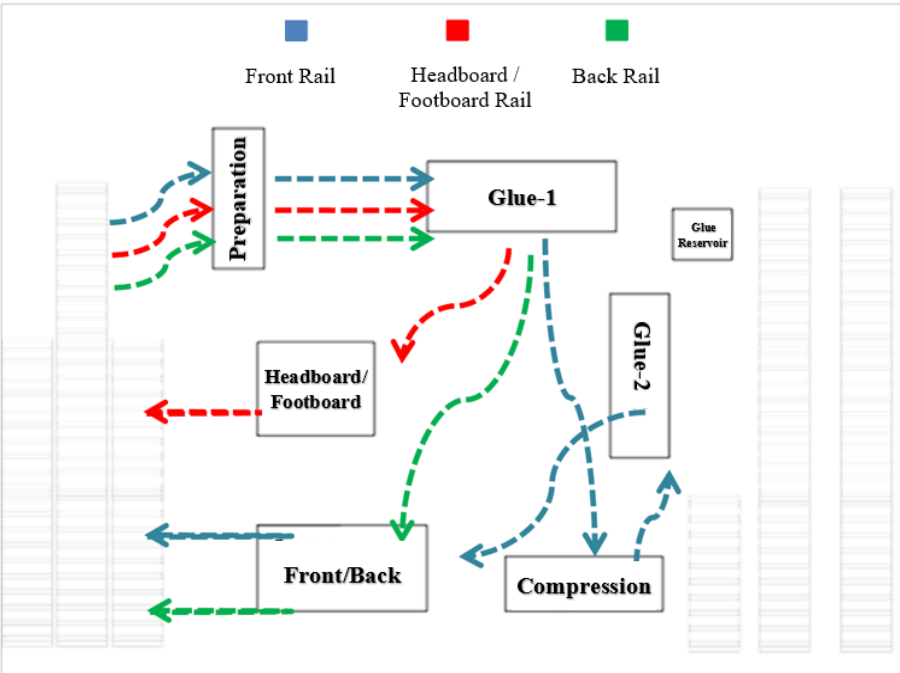

Figure 1. Current operations of the MOBAKS line

The current facility layout limits the effective utilization of both the workforce and production space. This structure results in the unnecessary transportation of parts over long distances, leading to wasted time, increased energy consumption, and heightened material handling costs. Moreover, the expansion of product variety and the rising demand from customers have outpaced the current capacity of the facility. This mismatch creates delays, backlogs, and reduced responsiveness to orders. Interruptions in production flow caused by bottlenecks and process inefficiencies further exacerbate the situation. An additional challenge lies in the use of high-power machinery for simple tasks. Meanwhile, the components of newly developed modules require prolonged machining times on standard CNC machines. This contributes to extended cycle times, delays in the production line, and reduced overall throughput. Deviations from standard work definitions, coupled with a lack of streamlined processes, lead to defects and increased customer dissatisfaction. The growing number of customer complaints highlights the pressing need for improvement initiatives.

As part of this study, a needs analysis is conducted by evaluating the current production plans for child beds alongside medium- and long-term strategies for future growth. A detailed assessment of the production efficiency of machines and workstations is carried out to identify areas for improvement. Based on the processing steps of the production components, alternative layouts are evaluated. Interactions between the machines are examined. Figure 2 presents the current route analysis of the considered line and a relationship diagram for the machines. The left side of the figure (⟵) shows the defined routes and the total Kanban quantity for each route. The most frequently used routes are B-B-C (540) and B-D-E (459), indicating critical material flows within the system. The right side of the figure (⟶) shows a relationship matrix detailing the number of direct transitions between the machines. The highest values are observed in the flows between B-C (954), D-E (465), and B-D (465). These figures point to a highly intensive workflow among these machines, underscoring the importance of positioning them in close physical proximity to ensure an efficient layout design. With the addition of a new area to the layout, alternative layout configurations are identified.

Route	Kanban Quantity
B-B-C	540
B-D-E	459
B-C-G	155
B-C	122
P-G	111
B-F	82
B-B-C-C-F	85
B-C-F	52
F-C	48
B-G	35
I-F	30
M-F	25
F	17
K-E	8
P-F	7
L-F	6
O-H-E	6
J-D-E	6
N-E	6
K-F	6
P-E	4
B-B-F	4
B-B	4
B-D-K-K-C-E	3
B-D-K-E	3
R-H-E	3

Machine	A	B	C	D	E	F	G	H	I	J	K
A						17					
B			**954**	**465**		86	35				
C					3	137	155				
D					**465**						6
E											
F			48								
G											
H					9						
I						30					
J				6			47				
K			3		11	6					
L						6					
M						25					
N					6						
O							6	6			
P					4	7	**220**				
R								3			

Figure 2. Current route analysis and machine relationship diagram for the MOBAKS line

3.2 Decision-making framework

This study employs a two-phase decision-making methodology to handle the facility layout problem. In the first phase, the fuzzy AHP procedure is applied to assess the importance of criteria influencing facility layout decisions. Fuzzy AHP generates criteria weights that reflect their significance in achieving the facility's operational objectives. Building on these weights, the second phase utilizes the fuzzy EDAS procedure to prioritize facility layout alternatives. Fuzzy EDAS evaluates each alternative's performance by analyzing its distance from the average solution, accounting for both positive and negative deviations. Sensitivity analysis is performed by varying the criteria weights to observe the stability of ranking outcomes. Additionally, comparative analysis is conducted using the fuzzy ARAS method.

An expert team is established to evaluate the decision elements of the model. The selection of experts is based on their domain-specific knowledge and prior experience in relevant decision-making processes. Three alternatives (denoted as A1, A2, and A3) are analyzed to identify the most effective solution. The criteria defined for evaluating the alternatives are total walking distance (C1), distance for cutting and drilling (C2), distance for roofless bedframe (C3), total rail savings (C4), compatibility with other machines (C5), and flexibility (C6).

3.3 Prioritization of evaluation criteria

Prioritizing evaluation criteria is a critical step to ensure that decisions align with operational goals and long-term efficiency. This study uses fuzzy AHP to prioritize the criteria influencing layout selection decisions. The fuzzy AHP process involves the pairwise comparisons of the criteria. The experts assess the importance of each criterion using linguistic terms provided in Table 1. These linguistic terms are subsequently converted into triangular fuzzy numbers for mathematical calculations.

Table 1. Linguistic terms and fuzzy numbers to evaluate the criteria (Ali Sadat et al., 2021)

Code	Linguistic term	Fuzzy number
1	Equally important	(1, 1, 1)
2	Equally to slightly more important	(1, 2, 3)
3	Fairly more important	(2, 3, 4)
4	Fairly more important to highly important	(3, 4, 5)
5	Highly important	(4, 5, 6)
6	Highly important to very highly important	(5, 6, 7)
7	Very highly important	(6, 7, 8)
8	Very highly important to absolutely more important	(7, 8, 9)
9	Absolutely more important	(8, 9, 10)

The pairwise comparisons are arranged in a fuzzy matrix (Table 2). To ensure consistency and reliability, the consistency ratio of the pairwise comparisons is calculated using the classical AHP consistency check procedure (Saaty 1977). Since the calculated value is below the threshold of 0.1, the evaluations are considered consistent and acceptable. Fuzzy AHP calculates the weights of the criteria based on the created matrix. These weights are then used to rank the criteria and guide the subsequent evaluation of the layout alternatives. The resulting weights are presented in Figure 3.

Table 2. Fuzzy pairwise comparison matrix

Criterion	C1	C2	C3	C4	C5	C6
C1	(1, 1, 1)	(2, 3, 4)	(2, 3, 4)	(1, 1, 1)	(0.25, 0.33, 0.50)	(0.25, 0.33, 0.50)
C2		(1, 1, 1)	(1, 1, 1)	(0.25, 0.33, 0.50)	(0.17, 0.20, 0.25)	(0.17, 0.20, 0.25)
C3			(1, 1, 1)	(0.25, 0.33, 0.50)	(0.17, 0.20, 0.25)	(0.17, 0.20, 0.25)
C4				(1, 1, 1)	(0.33, 0.50, 1.00)	(0.33, 0.50, 1.00)
C5					(1, 1, 1)	(0.25, 0.33, 0.50)
C6						(1, 1, 1)

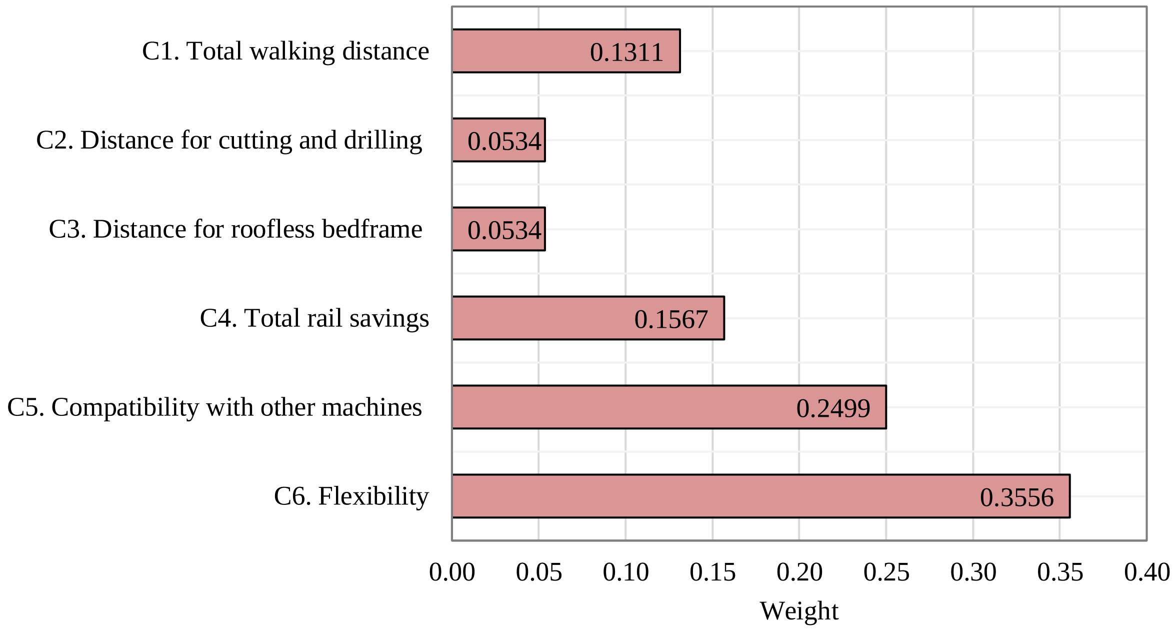

Figure 3. Importance weights of the criteria

The calculated weights reveal the importance of each criterion in the facility layout decision-making process. Flexibility emerges as the most critical criterion, accounting for 35.56% of the total weight. This result underscores the importance of a layout that can adapt to changing production demands. The high priority given to flexibility highlights the facility's need to remain agile and responsive to future operational changes. The second most significant criterion is compatibility with other machines, with a weight of 24.99%. Proper machine alignment and interaction prevent workflow bottlenecks, minimize downtime, and improve overall operational efficiency. These insights guide the selection of the optimal layout alternative to meet the facility's strategic objectives.

3.4 Prioritization of alternatives

The selection of the optimal facility layout requires a systematic evaluation of alternatives based on predefined criteria. The study employs fuzzy EDAS to prioritize three layout alternatives. The experts evaluate the performance of each alternative against all the criteria using linguistic terms provided in Table 3. These qualitative assessments are subsequently converted into fuzzy numbers for use in the fuzzy EDAS calculations. The resulting decision matrix for the alternatives is presented in Table 4.

Table 3. Linguistic terms and fuzzy numbers to evaluate the alternatives (Ali Sadat et al., 2021)

Code	Linguistic term	Fuzzy number
1	Very bad	(1, 1, 3)
2	Bad	(1, 3, 5)
3	Medium	(3, 5, 7)
4	Good	(5, 7, 9)
5	Very good	(7, 9, 11)

Table 4. Decision matrix for the alternatives

Criterion	A1	A2	A3
C1	(1, 3, 5)	(1, 1, 3)	(1, 3, 5)
C2	(3, 5, 7)	(1, 1, 3)	(1, 3, 5)
C3	(5, 7, 9)	(1, 3, 5)	(3, 5, 7)
C4	(1, 1, 3)	(3, 5, 7)	(1, 3, 5)
C5	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)
C6	(1, 1, 3)	(1, 3, 5)	(5, 7, 9)

For each criterion, the average performance score across all the alternatives is computed in fuzzy and crisp forms. This average serves as the reference point for calculating the distances. After determining the average solution for each criterion, the PDA and NDA matrices are formed. These matrices provide a structured representation of how each alternative performs relative to the average values for all the criteria. Specifically, the PDA matrix highlights the degree to which each alternative exceeds the average performance, while the NDA matrix captures the extent to which alternatives fall short. For each alternative, the individual PDA and NDA values across all the criteria are summed and normalized, as outlined in Steps 4 and 5 of the fuzzy EDAS procedure. These results are then used to determine the final performance of each alternative. The outcomes of the fuzzy EDAS analysis are presented in Table 5.

Table 5. Fuzzy EDAS results

Variable	A1	A2	A3
$\widetilde{sp}_i$	(-0.23, 0.09, 0.36)	(-0.10, 0.10, 0.26)	(-0.39, 0.50, 1.25)
$\widetilde{sn}_i$	(-0.23, 0.50, 0.95)	(-0.66, 0.19, 1.05)	(-0.22, 0.00, 0.27)
$\widetilde{nsp}_i$	(-0.49, 0.19, 0.78)	(-0.21, 0.21, 0.57)	(-0.85, 1.08, 2.69)
$\widetilde{nsn}_i$	(-1.20, -0.17, 1.54)	(-1.45, 0.57, 2.53)	(0.38, 1.00, 1.51)
$\widetilde{as}$	(-0.85, 0.01, 1.16)	(-0.83, 0.39, 1.55)	(-0.23, 1.04, 2.10)
as	0.0844	0.3742	0.9872
Ranking	3	2	1

A3 is identified as the best-performing option among the evaluated alternatives. The performance of A3 aligns closely with the decision-making objectives, making it the most suitable choice for implementation. The decision-makers should proceed with the implementation of A3 (Figure 4), as it demonstrates the best potential for improving production efficiency and meeting operational objectives.

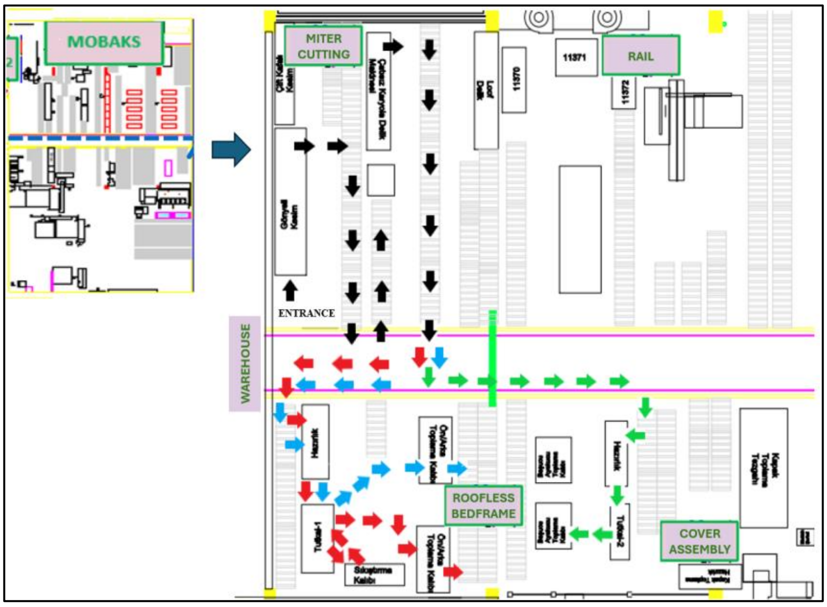

Figure 4. Optimal layout option

3.5 Sensitivity analysis

Sensitivity analysis is an essential process for evaluating the reliability of decision-making outcomes. By modifying the weights of evaluation criteria, this analysis examines how such changes influence the ranking of alternatives. In this study, sensitivity analysis is performed by interchanging the weights of two criteria while keeping the weights of all other criteria constant. The weights assigned to two criteria are swapped, and the fuzzy EDAS procedure is reapplied to assess whether the alternative rankings are affected. Each scenario represents a weight adjustment between two criteria. As shown in Figure 5, A3 consistently ranks as the best-performing option. This outcome confirms the reliability of the obtained ranking.

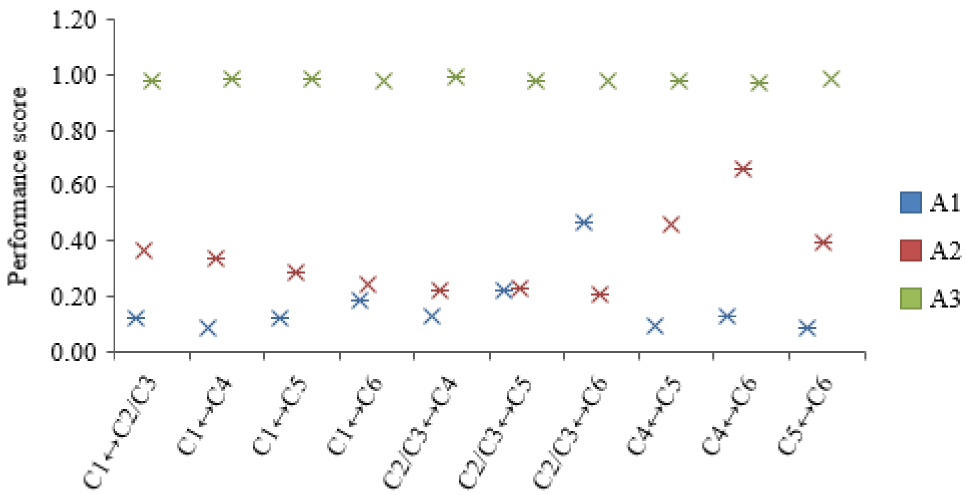

Figure 5. Sensitivity analysis results

3.6 Comparative analysis

Comparative analysis is a systematic approach used to validate the results of decision-making processes by evaluating alternatives through multiple methods. The primary goal of this analysis is to ensure the robustness, reliability, and consistency of the rankings or decisions obtained. In this study, fuzzy ARAS is used to perform the comparison analysis of the alternatives to validate the results obtained through fuzzy EDAS. Mathematical details of fuzzy ARAS can be found in the literature (Heidary Dahooie et al., 2022). The same criteria and their weights are used in this analysis to ensure consistency. As shown in Figure 6, the results of fuzzy ARAS are consistent with those obtained using fuzzy EDAS. The alignment of the results underscores the suitability of A3 as the optimal alternative.

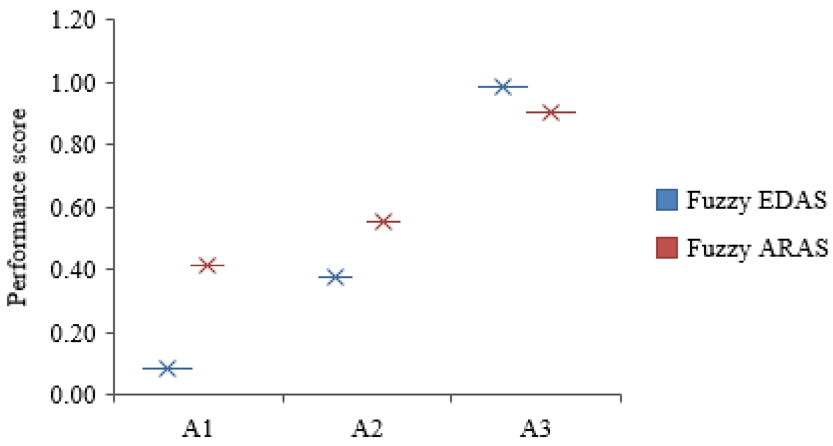

Figure 6. Comparative analysis results

4 Conclusion

This study focuses on evaluating and prioritizing layout alternatives for a furniture manufacturing facility in Türkiye. An integrated decision-making methodology combining fuzzy AHP and fuzzy EDAS is employed. The fuzzy AHP procedure is used to determine the importance of various criteria influencing facility layout decisions. The fuzzy EDAS procedure is used to evaluate and rank the identified facility layout alternatives. The results of the analysis highlight several significant improvements achieved through the selected layout configuration:

- Flexibility and compatibility with other machines are identified as the top two criteria, with weights of 35.56% and 24.99%, respectively. Layout option A3 demonstrates the highest performance, scoring 0.9872 and accounting for 68.28% of the total. Layout option A2 follows with a score of 0.3742, representing 25.88% of the total, while layout option A1 ranks last with a score of 0.0844, accounting for 5.84% of the total.
- The selected layout significantly enhances production efficiency and streamlines processes. It reduces bottlenecks in miter cutting operations and eliminates glue transportation between the roofless bedframe and cover assembly areas.
- The production distance for product components decreases by 210 meters, while active rail length increases from 55 to 90 meters. The assembly time for rail components decreases by 13.8 minutes. Reallocating tasks from CNC machines to lower-power equipment saves approximately 25,640 kWh annually. The layout also enables simultaneous production of multiple components.
- The findings of this study are consistent with prior research that employed various methods to enhance facility layouts. For instance, Erden et al. (2016) used fuzzy

axiomatic design in a furniture company to optimize layout and improve workflow. Similarly, Savsar and Aldehaim (2020) applied the CRAFT algorithm to reduce interdepartmental backflows and material handling costs. Lins et al. (2021) integrated a (re)layout strategy into a cleaner production initiative, increasing area efficiency by 33.33% and reducing waste. İnce and Taşdemir (2024) combined AHP, PROMETHEE, and CORELAP to create a layout that cut handling costs and improved flow while keeping managers close to operations. Our study aligns with these efforts in its approach and outcomes.

- This study provides a valuable contribution to the field of facility layout optimization by presenting an integrated decision-making framework. The study results demonstrate significant operational improvements, including reduced production distances, enhanced energy efficiency, minimized bottlenecks, and accelerated assembly processes. This research not only offers a robust solution for the furniture manufacturing sector but also serves as a valuable reference for other industries facing similar optimization challenges.
- Future research can expand upon this work by incorporating additional criteria. The integration of artificial intelligence could enable real-time visualization of layout configurations under varying operational scenarios.

Author Contribution

Hilal Singer: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Abdullah Cemil İlçe:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Murat Bulca:** Conceptualization, Methodology, Writing – original draft. **Erkan Bayır:** Conceptualization, Methodology, Writing – original draft.

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Conflict of Interest Statement

The author declares no conflict of interest.

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Japanese design concepts and traditional joints for modern furniture

Oprea-Adrian Spanu[1], Emilia-Adela Salca Manea[1*]

ABSTRACT: Japanese culture presents refinement, simplicity, aesthetics, and balance. It shows how nature and aesthetics can be integrated into the living space. The architecture of the Japanese house is characterized by sliding doors and partitions that can be removed to create large, open, and flexible spaces. Traditional furniture has a simple beauty and functionality that fits perfectly with Japanese life and philosophy. Japanese wood products are uniquely crafted without nails or screws, relying on precise joinery for durability. Such a technique yields very durable and aesthetically pleasing furniture pieces. Japanese wood techniques, employing the art of Japanese woodworking, offer training in the wood workshop, teaching patience and respect for nature. This study reviews and highlights Japanese design concepts along with a selection of traditional jointing techniques for furniture. Based on them, a modern table inspired by the Torii Gate was designed. Therefore, modern furniture inspired by such concepts can stand the test of time.

Keywords: Design, Furniture, Japanese joints

Modern mobilyalar için Japon tasarım konseptleri ve geleneksel birleştirmeler

ÖZ: Japon kültürü incelik, sadelik, estetik ve denge sunar. Doğanın ve estetiğin yaşam alanına nasıl entegre edilebileceğini gösterir. Japon evinin mimarisi, büyük, açık ve esnek alanlar yaratmak için çıkarılabilen sürgülü kapılar ve bölmelerle karakterize edilir. Geleneksel mobilyalar, Japon yaşamı ve felsefesiyle mükemmel bir şekilde uyuşan basit bir güzelliğe ve işlevselliğe sahiptir. Japon ahşap ürünlerinin tasarımında çivi veya vida kullanılmadığı bilinen bir gerçektir ve bu da onları hassas bağlantılara sahip olmaları nedeniyle çok benzersiz kılar. Böyle bir teknik, çok dayanıklı ve estetik mobilya parçalarıyla sonuçlanır. Japon ahşap işçiliği sanatını kullanan Japon ahşap teknikleri, ahşap atölyesinde eğitim sunarak sabrı ve doğaya saygıyı öğretir. Bu çalışma, Japon tasarım konseptlerini ve mobilyalar için geleneksel birleştirme tekniklerinden bazılarını inceler ve vurgular. Bunlara dayanarak, Torii Kapısı'ndan esinlenen modern bir masa tasarlanmıştır. Dolayısıyla bu konseptlerden ilham alan modern mobilyalar zamana meydan okuyabiliyor.

Anahtar kelimeler: Tasarım, Mobilya, Japon bağlantıları

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1 Introduction

Interior design, specifically Japanese furniture, has become a source of inspiration for designers all around the world. Japanese culture is known for its refinement, simplicity, aesthetics, and balance. Japanese-inspired interior design integrates nature and aesthetics into living spaces. The basic elements of Japanese interior design are: simplicity, the use of nature as a source of inspiration, the colour palette, the architecture and flow of the space, and traditional furniture items by using specific traditional techniques (Fujita, 2003). When all of these come together, an environment where balance and harmony prevail emerges. This study reviews and highlights Japanese design concepts along with a selection of traditional jointing techniques for furniture. Based on them, a modern table inspired by the Torii Gate was designed.

2 General Concepts of Japanese Design

2.1 Simplicity and minimalism

Simplicity is one of the most important characteristics in creating a piece of furniture, and that principle is reflected in every aspect of the design (Hirano, 1991; Breyer, 2020). The furniture is reduced to its essence with clear shapes and simple lines making the space clean and uncluttered. This approach enables energy to flow freely, creating a calm and peaceful environment (Juniper, 2003).

Simplicity is also highlighted in the choice of colour palettes used in Japanese design, such as shades of white, gray, and natural wood tones, generally neutral hues. These colours create an ideal background for positioning furniture within a room. Such a space becomes an "open cavity" that invites contemplation and relaxation (Nitschke, 1993).

2.2 Integration of nature

The Japanese have a deep connection with nature, which strongly informs their design philosophy (Engel, 1985). Natural elements such as stone, wood, and bamboo are generously integrated into built spaces. Wood is frequently used to create a warm and welcoming environment in Japanese-style interiors. Furniture items like low tables (*chabudai*) and backless chairs (*zaisu*) contribute to this natural ambiance. They are typically dark-coloured, made from wood or bamboo, and feature a low profile and flexible character to ensure they can be easily moved, especially important in spaces with sliding walls (*fusuma*).

The concept of *shinrin-yoku*—or "forest bathing"—is a modern interpretation of this ancient connection to nature, emphasizing the psychological and physiological benefits of immersing oneself in natural surroundings (Li, 2018). Similarly, *tsubo-niwa* or Japanese courtyard gardens are small green spaces often found within homes that bring nature indoors. These gardens promote relaxation and reinforce the connection between inhabitants and the natural world (Keane, 1996).

2.3 Japanese colour palette

The colours used in Japanese design are inspired by the natural environment of Japan. For example, gray and black highlight the rocks and stones, white and beige highlight the snow and cherry blossoms, shades of green represent the luxuriant vegetation of Japan, and blue highlights the ocean and clear sky (Young, 2008). These colours combine perfectly to create a calm, balanced image, adding depth and texture to spaces and furniture.

Natural lighting plays an important role in the design, thanks to large windows and shoji paper panels, which allow natural light to enter the room, thus giving a bright and airy space.

Artificial lighting uses lamps with warm and diffused light, with a minimalist design or suspended, made from natural materials such as wood or paper (Jodidio, 2005). Indirect lighting through cornices suits Japanese design through the modest light and the atmosphere it gives to the space. This type of lighting helps small rooms and is the right choice to maintain the minimalist and simplistic style. Table 1 displays examples related to these three concepts.

Table 1. General concepts of Japanese design (Spanu, 2024)

No.	Definition	Example
1	Simplicity and minimalism	
2	Integration of nature	
3	Colour palette	

2.4 The architecture and flow of space

The architecture of the Japanese house is characterized by sliding doors and partitions that can be removed to create large, open, and flexible spaces (Jodidio, 2005). This design encourages connections between different areas of the house, especially with the surrounding terraces and gardens.

The living room is inspired by the rooms specific to the tea ceremony with very low furniture pieces. The dining table is used while kneeling or on cushions, and the armchairs and sofas must be at floor level. A mattress filled with rice threads called *Tatami* is used for the floor, which is placed across the entire surface of the room.

The Japanese bedroom must be strictly functional, the furniture pieces must not be cramped, and therefore the bed must be very low, or even a mattress is set directly on the floor. The colours must be among the simplest, cream, black, and brown, both for the walls and accessories.

The kitchen is planned to be always kept clean. Wooden or stone furniture, with imperfections, creates an exemplary space, one of the strengths of Japanese design, thanks to the *wabi-sabi* technique, a concept that brings to mind the beauty that is found in imperfection (Juniper, 2003).

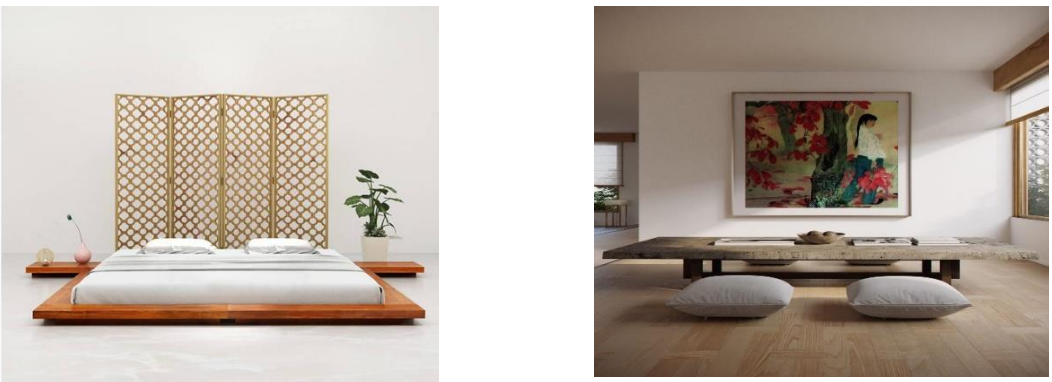
The bathroom is a space where you can disconnect at any time of the day. Japanese Ofuro bathtubs are specific to Japanese culture and Zen philosophy and are used for relaxation sessions. Stone and wood elements with diffused lamps or natural light are used for the walls in the bathrooms.

The hallway of the Japanese house is considered an important space because it is a space for receiving guests, and therefore, they show their respect for their fellow humans through elegance and refinement. Low cabinets for shoes or wooden chests of drawers can be placed in this space to support the green plants.

2.5 Specific traditional Japanese furniture

Traditional furniture has a simple beauty and functionality that fits perfectly with Japanese life and philosophy (Yoshida, 2009). Cabinets and storage furniture are generally built without handles to maintain this minimalist character. An important element in furniture design is the *Futon* bed, which consists of a quilted mattress (*shikibuton*) and a sheet (*kakebuton*) that serves as a blanket. This combination is placed directly on the *Tatami*. The frame of the bed in Fig.1a is made of acacia wood which gives it stability and robustness.

Each stage of construction is done with skill, and each bed becomes unique in its way. Another element of furniture design is the *chabudai* or low Japanese tables (Fig.1b). These are perfect for serving tea and traditional food. Examples of modern Japanese interior design are presented in Table 2.



a. Futon bed   b. Low table-Chabudai

Figure 1. Specific Japanese furniture (Spanu, 2024)

Table 2. Examples of modern Japanese interior design (Spanu, 2024)

No.	Description	Example (room and furniture)
1	Living room	
2	Bedroom	
3	Kitchen	
4	Bathroom	
5	Hall	

2.6 Modern trends in furniture design and examples of successful projects

Japanese culture is based on simplicity and minimalism, so furniture should be as simple as possible. A spacious and airy room with furniture within the strictest limits is much more beautiful and welcoming than one loaded with furniture items (Adriasola et al., 2016; Jodidio, 2005). Aligned with the modern trends felt nowadays in design, the contemporary Japanese style can be highlighted by the following elements (Spanu, 2024):

• **Sophisticated minimalism** is a major furniture design style that emphasizes quality and durability with the slogan "less is more" (Juniper, 2003).

• **Japandi style** represents a cultural fusion of two different interior design styles. This style is distinguished by combining the traditional Japanese style with the minimalist and soothing Scandinavian design. Japandi style became popular in 2017, when it was intended to express minimalist technique and aesthetics in a complementary way.

• **Neo Art-Deco** represents a contemporary style in vogue and is also called the return to glamour. It is a trend that emphasizes details such as wallpaper, stucco in a room, so that the opulent furniture stands out.

• **Biophilic design** is a style that brings nature into people's homes and can contribute to creating a cleaner and more relaxing environment.

• **Eclectic style** (the new normal) is a style that breaks with the concept that everything has to fit together perfectly, so it is a mix of styles, textures, and colours that can create a unique and welcoming space with a lot of personality (Juniper, 2003). It offers the freedom to combine old with modern elements, synthetic materials with natural or bright colours with neutrals.

• **Inclusive design** is a growing trend to meet the needs of all residents including those with disabilities. Characteristic elements are ramps, handles, or adaptable furniture that make the surrounding space more functional.

Traditional Japanese carpentry works on the principle of respecting nature. Out of the world-renowned furniture creators, we can name George Nakashima and Hisao Hanafusa.

George Nakashima used to say that a tree is our most intimate contact with nature. His entire philosophy and work were based on this concept. He believed that a tree should be cut down when it reaches maturity, because then, like man, it will die and return to the ground. Thus, cutting it down and using it to make useful objects in the house gives it the chance to live another life. He worked wood in a special style, different from other woodworkers. He preferred the part where the tree trunk forked, because that's where the wood had the most beautiful pattern (Nakashima, 1981).

Tabletops made from a single slice of wood were brought into Nakashima's furniture design, and the use of wooden bow ties to bridge cracks or weak spots between them became his signature (Fig. 2a). Nakashima designed a lot of furniture, but he never signed it. He created works for famous people, and his pieces are housed in famous museums in the US and Japan.

Hisao Hanafusa is a carpenter who uses traditional techniques, saying that you have to work with nature to achieve your goals. This statement helps him preserve the natural shapes of wood without interfering with them. He develops the idea of using wood from the base of the tree upwards, thus preserving the order of nature. The creative process begins with the tree, which is cut and sliced into planks that are left to dry for up to 10-20 years, after which he chooses the plank and nature tells him what to do with it. Therefore, you look for a project that fits the nature (Fig. 2b).

a. Table created by George Nakashima (URL 1, 2025)

b. Table created by Hisao Hanafusa (URL 2, 2025)

Figure 2. Different designs for modern furniture

3 Japanese wood jointing and the SOA table design

3.1 Brief history of the wooden Japanese joints

Japanese joinery is a traditional woodworking technique that has been used for centuries in Japan (Brown, 2011). It is known for its intricate craftsmanship and precision, resulting in strong and durable wooden joints and structures (Engel, 1985). *Kabuse-meji-tsugi* represents the art of Japanese joinery. In this technique, the craftsman considers the functional along with the aesthetic line, but the wood species to be used are granted with respect, and wood colour, pattern, and texture are relevant for the designed work (Takenaka, 2006). This attention to detail ensures that the joint not only serves its purpose but also enhances the overall beauty of the structure. In addition, *kabuse-meji-tsugi* is not limited to just straight joints; curved and angled joints can be obtained as well. Such structures are found in various architectural elements such as roofs, beams, furniture, or door frames (Yoshida, 2009).

The origins of Japanese carpentry go back to the Asuka and Nara periods (VI-VIII centuries) when Japan was heavily influenced by the Chinese culture (Ito, 1998). Continuing during the Heian period (IX-XII centuries), the art of Japanese joinery flourished and new techniques appeared (Fujita, 2003).

Later on, Japanese carpentry underwent further advancements during the Kamakura period (XII-XIV centuries). Zen Buddhism greatly influenced the philosophy behind carpentry, emphasizing its simplicity and harmony with nature.

No nails, screws or glue are used for traditional Japanese woodworking, neither modern power tools. Such joints provide an exceptional durability to the resulting structures. In the case of constructions, the resistance to earthquakes is due to the absence of iron nails, which allows the joint to flex and support seismic forces. The craftsmen use a range of tools, all well-sharpened and accurate. Even though power tools are increasingly used instead, hand tools remain essential to achieve intricate joints in their project (Brown, 2011; Izuhara, 2020).

3.2 Specific Japanese wood jointing techniques

Japanese wood joining techniques for furniture are known for their refinement and accuracy, allowing the creation of durable and aesthetic furniture pieces without the use of nails or screws (Sato and Nakahara, 1995; Yoshida, 2009). Here are some of the most commonly used Japanese jointing techniques in wooden furniture construction:

- ***Kumiko***

Kumiko is a traditional Japanese method of joining wood, primarily used to create decorative patterns in wooden frames, such as *shoji* screens and other architectural elements (Seike, 1977). The history of this technique spans several centuries and reflects the craftsmanship and attention to detail characteristic of Japanese carpenters.

Kumiko originated in the Asuka period (538-710 AD), but became truly sophisticated during the Edo period (1603-1868). During this period, carpenters developed a wide range of intricate patterns reflecting Japan's cultural and aesthetic influences. The technique has been refined over the years, and craftsmen have passed down their knowledge from generation to generation.

Kumiko involves the accurate cutting and joining of small pieces of wood to create geometric patterns. It does not use nails or glue, but relies on precise joints that fit together perfectly. Some of the most common patterns include *asanoha* (hemp leaf) and *yosegi* (complex geometric patterns) (Fig.3a).

Kumiko is not only a decorative technique but also a symbol of traditional Japanese values such as simplicity, functionality, and respect for nature. Each pattern has its meaning, and the craftsmen place great emphasis on balance and proportion in their designs (Sato and Nakahara, 1995; Yoshida, 2009).

- ***Ari-Gata***

Ari-gata, also known as dovetail jointing, is one of the oldest and most appreciated wood jointing techniques in the Japanese tradition. This joint is known for its durability and strength, and is frequently used in the construction of wooden furniture and structures (Sato and Nakahara, 1995; Yoshida, 2009). The history of *Ari-gata* stretches back centuries with origins in the Yamato period (250-710 AD). The technique evolved as Japanese carpenters perfected woodworking methods influenced by the need to create strong structures without the use of nails or other metal materials which were rare and expensive.

The *Ari-gata* joint is characterized by its trapezoidal shape which resembles the tail of a dove (Fig. 3b). This special shape provides a robust connection that is resistant to separation forces, making it ideal for drawer corners and other joints that require high strength (Seike, 1977; Yoshida, 2009).

The *Ari-gata* technique is mainly used in furniture construction, such as drawers, boxes, and other furniture items that require strong corner joints. In addition to functionality, this technique also adds aesthetic value, showing the craftsmanship of the carpenter and respect for Japanese tradition.

- ***Hozo***

The *Hozo* technique, also known as mortise and tenon, is one of the oldest and most widely used woodworking techniques in the world. In Japan, the technique was perfected and became an essential element in the construction of buildings and furniture, reflecting the craftsmanship and attention to detail of Japanese carpenters (Sato and Nakahara, 1995).

The *Hozo* technique has ancient origins, having been used for thousands of years in various cultures to create durable and sturdy structures. In Japan, the technique was adopted and adapted to suit the specific aesthetic and functional requirements of Japanese architecture and carpentry. The first uses of the *Hozo* technique in Japan can be traced back to the Yayoi period (300 BC - 300 AD) when Japanese carpenters began to develop advanced methods of woodworking. During the Nara period (710-794) and Heian period (794-1185), the use of the *Hozo* joint became more sophisticated as Japanese carpenters began to build temples and other complex structures (Seike, 1977; Yoshida, 2009). During the Edo period (1603-1868), the *Hozo* technique reached a level of extraordinary refinement with Japanese carpenters developing numerous variations of the joint to suit different architectural and furniture applications. *Hozo* is widely used in the construction of traditional Japanese buildings such as temples, pagodas, and houses. It is also essential in the making of traditional Japanese furniture such as tables, chairs, and cabinets (Fig.3c).

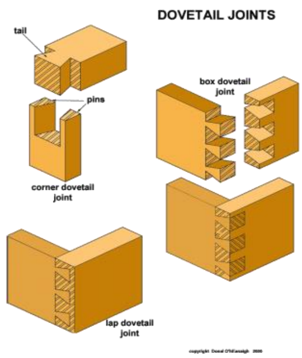
- ***Kanawa-Tsugi***

Kanawa-tsugi is a traditional Japanese method of wood joining used in construction and carpentry. This technique involves connecting two pieces of wood, usually at right angles, using a special type of mortise (Seike, 1977; Yoshida, 2009).
It is a joint used to extend the length of a piece of wood. The pieces of wood are cut and joined in a way that evenly distributes the tension, creating a strong joint, and it is often used in the construction of long furniture frames such as tables and benches (Fig.3d).

Kanawa refers to a key-shaped piece of wood while *tsugi* means joint. In this technique, a piece of wood is cut and shaped to fit where the two main wooden pieces meet. This involves an intricate cut to fit perfectly into the space between the two pieces of wood, thus ensuring a strong and stable connection (Sato and Nakahara, 1995).

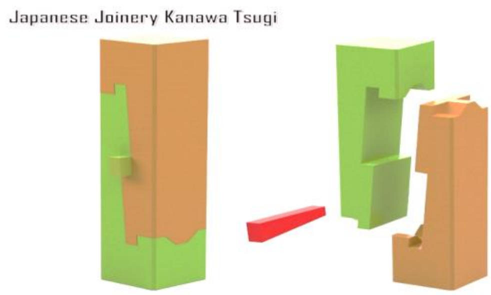
Kanawa-tsugi is valued for its simplicity, but also for its strength. This technique was developed over time in Japan and is still used today in many traditional and modern construction projects. Using this technique requires skill and precision, but the results can be impressive from an aesthetic and functional point of view.

a. Kumiko



b. Ari-Gata

c. Hozo



d. Kanawa Tsugi

Figure 3. Examples of Japanese jointing techniques (Spanu, 2024)

3.3 The SOA table design

The table is a Japanese concept inspired by the Japanese Torii Gate, which marks the entrance into a sacred place of a Shinto shrine in Japan.

The table is made of oak wood (*Quercus robur* L.) by using two types of Japanese joints, such as *Wari-kusabi* and *Hana-Sen* (Fig. 4 a-b). The *Hana-Sen* (draw pin joint) relies on a piercing locking pin while the *Wari-kusabi* (split wedge joint) uses a set of wedges pushed into corresponding slots at the end of the male component, effectively locking the assembly (Wall, 2021; Spanu, 2024). Two variants of the table in 3D modelling are presented in Fig.5.

The table is built starting from the legs up, towards the tabletop, it contains no screws. It was designed to be delivered in pieces and assembled according to a sketch attached to the project. The table is a prototype; it has a size of 900 * 500 mm and a height of 450 mm. Semi-professional tools have been used in a private workshop to produce it: a roughing machine, circular table saw, band saw, hand circular saw, mortising machine, and chisels. The sequences of processing are presented in Table 3. A manual sander was used for sanding, and Rubiomonocoat black oil was applied to obtain the final finishing (Fig. 6).

a. *Hana-Sen* b. *Wari-Kusabi*

Fig. 4. Typical joints used for the SOA table (Wall, 2021; Spanu, 2024)

a. Natural finishing b. Black finishing

Figure 5. 3D modelling of the SOA table (Spanu, 2024)

Table 3. Sequences of the processing in the workshop (Spanu, 2024)

		
1. Planning	2. Circular saw	3. Panel consolidation
		
4. Oblique cutting	5. Mortising	6. Band saw
		
7. Sanding	8. Manual cutting	9. Elements

	
10. Front view of the table	11. Side view of the table

a. SOA table (Spanu, 2024)

b. Torii Gate (URL 3, 2025)

Figure 6. Final product inspired by the Torii Gate

4 Conclusions

The research results are presented below in bulleted form.

- Sustainability is deeply rooted in the ethos of Japanese woodworking. Traditional wood-working craftsmen use local wood species such as Hinoki (Japanese cypress), Sugi (Japanese cedar), and Kiri (Paulownia) which have good workability and beauty. Therefore, the local ecosystems are well-supported by such a practice.
- The sustainability of Japanese woodworking resonates strongly with the contemporary global emphasis on environmental practices.
- The art of Japanese woodworking is a tradition where respect for material, precision of technique, and elegance come together and transcend borders, cultivating a connection with nature and heritage. It offers lessons in the wood workshop; it teaches patience and respect in the natural world.
- As a result, modern furniture can be based on such concepts and stand the test of time.

Author Contributions

Oprea-Adrian Spanu: Conceptualization, Project administration, Resources, Writing – original draft, **Emilia-Adela Salca Manea**: Supervision, Validation, Visualization, Writing – review & editing.

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The authors declare no conflict of interest.

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Integration of design for disassembly method using recycled mahogany material in modular furniture

Nurnajman Assyiraq Ibrahim[1*], Sheila Andita Putri[1]

ABSTRACT: This paper explores the Design for Disassembly (DfD) methodological approach in the furniture design process. Design for Disassembly is a product design strategy that enables a product to be disassembled for easier maintenance allowing cost-effective recovery of reusable components and materials, which are important for optimizing products for reuse and recycling at the end of their life cycle. The modular concept further enhances this approach by allowing for interchangeable parts enabling customers to repair and upgrade their furniture without needing a complete replacement. Furthermore, this paper provides an overview of Design for Disassembly approaches on furniture development as an effective tool for significant reduction for new raw materials using recycled mahogany material that result from adopting these practices. The main aim of this research is to support the current and future development in the field of disassembly, promoting a more sustainable utilization of resources, contributing to a circular economy and minimizing the environmental impact of furniture manufacturing.

Keywords: Design for disassembly, Sustainable waste management, Modular furniture

Modüler mobilyalarda geri dönüştürülmüş maun malzemesi kullanılarak sökme yöntemi için tasarımın entegrasyonu

ÖZ: Bu çalışma, mobilya tasarım sürecinde Demontaj İçin Tasarım (DiT) metodolojik yaklaşımını incelemektedir. Demontaj İçin Tasarım, ürünün daha kolay bakım için demonte edilmesini sağlayan ve yeniden kullanılabilir bileşenlerin ve malzemelerin maliyet etkin bir şekilde geri kazanılmasını sağlayan bir ürün tasarım stratejisidir; bu bileşenler, yaşam döngülerinin sonunda yeniden kullanım ve geri dönüşüm için ürünleri optimize etmek için önemlidir. Modüler konsept, değiştirilebilir parçalara izin vererek bu yaklaşımı daha da geliştirir ve müşterilerin mobilyalarını tamamen değiştirmeye gerek kalmadan onarmalarını ve yükseltmelerini sağlar. Ayrıca, bu çalışma, bu uygulamaları benimsemekten kaynaklanan geri dönüştürülmüş maun malzemesini kullanarak yeni hammaddeler için önemli bir azalma sağlayan etkili bir araç olarak mobilya geliştirmede Demontaj İçin Tasarım yaklaşımlarına genel bir bakış sunmaktadır. Bu çalışmanın temel amacı, demontaj alanındaki mevcut ve gelecekteki gelişmeleri desteklemek, kaynakların daha sürdürülebilir bir şekilde kullanılmasını teşvik etmek, döngüsel ekonomiye katkıda bulunmak ve mobilya üretiminin çevresel etkisini en aza indirmektir.

Anahtar Kelimeler: Demonte tasarım, Sürdürülebilir atık yönetimi, Modüler mobilya

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1 Introduction

The Indonesian Stock Exchange reports that the Indonesian furniture industry is experiencing growth in the First semester of 2024, furniture industry products contributing 1,1% towards GDP, with export performance of over 1,02 billion US dollar. As the Data Statista Market Insight projects, the 2028 Indonesian furniture market will reach 4,24 billion US dollar. The largest segment in this market is living room furniture, followed by home décor and bedroom products. Besides the market analysis, increasing population growth in Indonesian metropolitan cities demands an ever-increasing amount of space, leading to the creation of limited residential space. As a solution to limited land, an apartment is considered the best option for urban communities to live in the city. This condition causes a problem for residents to create comfort and functionality in a limited space. One way to solve this problem is by creating multifunctional and flexible furniture, so that the room can be used to its full potential without compromising any daily activities. As time goes by, innovation in furniture products is growing and developing along with the needs of users, one of which is the innovation is furniture with modular features. Modular design involves creating products by arranging sub-assemblies and components as separated building blocks known as modules, which can be configured and integrated to meet a various user needs and technical requirements. (Tseng et al., 2018). Modularity in product design, as described by Ulrich and Tung (1991) defined in two terms: (1) alignment between the physical structure and its functional elements, and (2) reducing incidental interactions among physical components. Ulrich (1995) also states that modular products or subassemblies have a one-to-one mapping between functional elements in the function structure and physical components of the product, ensuring that all components from various modules are separated. In other words, a module is a component with the same shape and a configuration according to the needs of its users.

A design process is essential when creating a product; the importance of the design process in a product will determine the success of the product. Design is concerned with creating items that people want. This process involves thought and execution in the design. Modern product design is a systematic, methodical, and directional creative activity. The design practice refers to the progression of the design and the sequence in which design tasks are completed. This process represents an integrated approach to identifying, analysing, and solving problems (Cheng, 2018). A good design must follow a plan that includes objectives concerning cost, performance, effort, chance of success and even aesthetics. The design process must take a closely evaluated path, starting from the statement of needs that are considered important until the functionality is achieved. Therefore, design requires a methodological approach. Methods involve the totality of approaches that can be employed to accomplish specific objectives across various fields. When people want to understand and change the world, they must participate in a range of cognitive and practical activities. The diverse techniques in these activities are collectively referred to as methods. No matter the task at hand, it is essential to have appropriate methods, as the effectiveness or disadvantages of these methods directly influence the success or failure of the work (Cheng, 2018).

Design for Disassembly is one of the design methods used in the manufacturing industry. Mule (2012) states that Design for Disassembly is a method that allows products to be diassembled for easier maintenance, repair, and the recovery and reuse of components and materials. This method aims to reduce the environmental impacts while maximizing the end-of-life value of the product. Rios et al., (2015) define DfD as a method that aims to ease deconstruction processes through planning and design. Deconstruction is the process of dismantling a product recover the functionality of the disassembled materials so that it can be reused. The deconstruction technique essentially changes the conventional waste management process. The Design for Disassembly process is a crucial strategy for conserving new raw materials in order to reduce waste, extend the life of materials, and optimise their use.

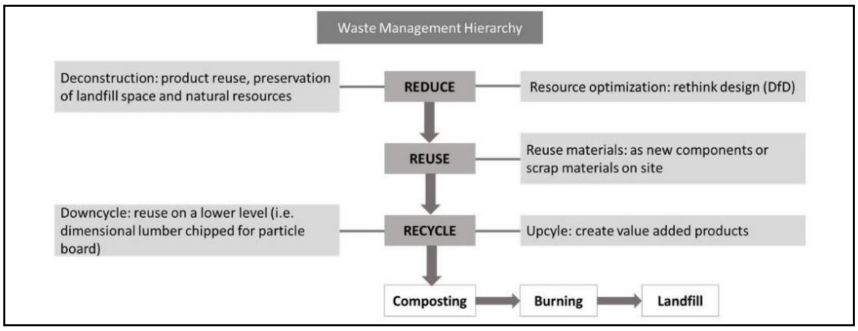

Figure 1. Waste Management Hierarchy (Rios et al., 2015)

Design for Disassembly functions as Reduce, Reuse, and Recycle (3R) process with the goal of eliminating the urgency of composting, burning, and waste disposal.

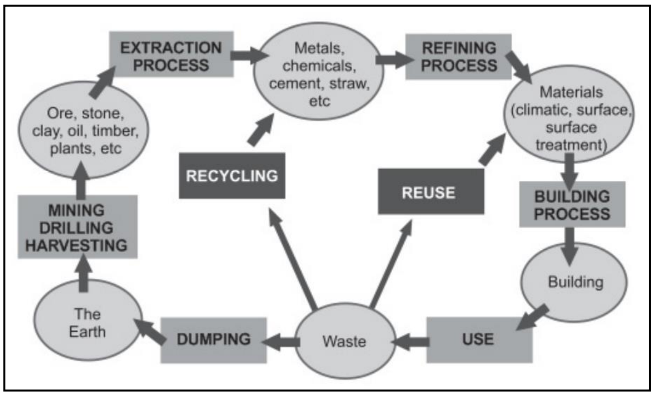

Figure 2. Closed Loop Material (Rios et al., 2015)

Design for Disassembly is an important concept in the effort to create a closed loop material system. The Closed Loop approach is similar to natural biologic metabolical processes where “waste” is transformed into “nutrients”. The continuous cycle is referred to as technical metabolism, enabling waste to be recycled and reused into new nutrients, which can be new materials or uses to creating other products. (Rios et al., 2015). As will be discussed in this paper, the focus is on designing furniture by implementing the Design for Disassembly method. Research on the application of this method remains quite limited; therefore, this study aims to contribute to the existing literature, validate the effectiveness of this approach in the furniture products design process, and create a positive impact on both users and the environment.

2 Material and Method

This study utilizes a qualitative research methodology. Qualitative research systematically collects and analyzes a variety of empirical materials such as observation, interview, case studies, and document analysis and is used as an approach to uncover perceptions and events realistically and comprehensively in a natural environment. (Denzin & Lincoln, 2008).

Corbin and Strauss (2008) In Bowen (2009) defines document analysis as a systematic approach to reviewing or evaluating documents. Similar to other qualitative research methods, it involves analyzing and interpreting data to extract meaning, improve understanding, and build empirical knowledge. Document search was applied in the analysis of the data in terms of Design for Disassembly approach, guidelines, framework and strategy. The findings from this analysis were then applied to the furniture production process based on Design for Disassembly principles.

3 Applying design for disassembly method in furniture design process

In Escoto-Munoz (2020), Mule (2012), Galantucci et al., (2004), and Dowie-Brahma (2001), there are three essential factors that designers should consider to applying disassembly method

- Material Selection.
- Fasteners and Connectors.
- Product Structure and Component design.

3.1 Material selection

Material selection is a crucial element in product design. In the Design for Disassembly method, the selection of materials must not compromise the structural requirements of the design, especially when using a variety of materials. Mule (2012) states several guidelines for material selection, explained as follows:

- Select materials that reduce pollution during extraction, processing, installation, recycling, and disposal.
- Limit the variety of materials in each component.
- Decrease the total number of various materials in product.
- Ensure that materials can be easily recycled during disassembly whenever possible.
- Design parts for remanufacturing and reuse after disassembly.
- Facilitate classification of material.
- Select materials that are compatible with one another.
- Reduce the overall diversity of materials.
- Optimize the use of all materials.
- Avoid contaminant material.

In this study, researchers utilized mahogany wood waste sourced from the INPI House, a local MSME (Micro, small and medium enterprises) producing and specializes in creating signage and displays for commercial spaces, such as cafés, restaurants, hotels, gallery rooms, offices, clinics and the other sector within the hospitality industry.

Figure 3. INPI House Workshop

Using mahogany as the main material, INPI House uses 3 m^3 of mahogany every month, which is equivalent to 180 mahogany tree trunks. This results in 10% of the wood not being used due to faulty tree trunks and materials that do not meet production quality standards.

Figure 4. INPI House Wood Waste

3.1.1 Waste management

The production process creates waste in the form of large pieces, small pieces and sawdust with different sizes. Waste management was categorized according to four waste types in Table 1.

Table 1. INPI House Waste Management

Waste source	Waste product	Waste size	Waste management
Deformed Mahogany Wood Material received from the supplier	Wooden Planks	15 cm x 1m to 15 cm x 2 m	N/A
Wood Processing Residues	Sawdust	N/A	Utilized for tofu factory furnace combustion
Production Process	Small sized pieces of wood	1 cm x 2 cm to 20 cm x 15 cm	Utilized for dowels, joints, moulds, and other wood working supportive equipments
Finished Products that fail the required qualification	Finished Wood Products	5 cm x 5 cm to 20 cm x 30 cm	N/A

As a result, INPI House continues to underutilize its potential for waste disposal; in other words, INPI House does not have any effective waste management practices. In this case, a significant portion of the wood waste can be recycled to create new products.

Rios (2015) describes Design for Disassembly as an essential concept for closing material loops and transforming waste into new materials. Recycled mahogany material was implemented to furniture design process using deformed wood and production process waste with the aim to reduce the use of new material and emphasize a closed-loop system.

3.2 The Selection and use of connector and fastener

Connectors and fasteners play a crucial role in joining components and sub-assemblies in designs intended for manual disassembly. Although different methods can be used to minimize the time needed for disassembling parts, designers need to consider several factors:

- Minimize the number of fasteners and connections in an assembly.
- Choose fasteners and connections that allow quick and easy disassembly.
- Limit the variety of fasteners used within an assembly.
- Utilize snap fit fasteners whenever possible.
- Use standardized fasteners.
- Design assemblies to accommodate common hand tools for disassembly.
- Avoid using incompatible adhesives that can negatively impact material recyclability.
- Prioritize fasteners and connectors over hard wired connectors.
- Aim to minimize both the quantity and diversity of fasteners.

By prioritizing sustainable and environmentally friendly principles, this furniture design deliberately avoids conventional fasteners and connectors such as bolts, screws, locks, nails, or other commonly used connectors in the furniture industry. To enhance this approach, the design utilizes joints that serve as connectors between components or sub-assemblies.

3.2.1 Joints

Joints are a crucial connection between two or more components of wood, essential to create a strong and functional structure. In this particular design, the sliding dovetail joint is applied, which is a specific type of wood joint used to connect two components of wood. This joint consists of two parts, with one part of wood having a prominent dovetail shaped projection and the other part of wood featuring channels or slots that imitate the shape of the projection.

Figure 5. Dovetail Joint

To enhance quick and easy disassembly, sliding dovetails are utilized to connect modules in various configurations. In traditional timber construction, a dovetail joint is used to connect stuctural components in the longitudinal direction to extend the length of timber tension. These joints are also employed to join two elements at right angles or nearly so. It is also used as a corner joint in carpentry and joinery. The specific geometry of the dovetail joint allows it to withstand both compression and tension forces along the longitudinal axis of the element. The precise fit of the dovetail joints keep maintain the alignment of the elements without the use of screws, nails, or other fasteners. (Dounas & Spaeth, 2014).

3.3 Product structure and component design

Product structure and component design that allow easy disassembly for maintenance will also enhance the recycling process initiated by the designer. Some applicable principles include:

- Facilitate quick and cost-effective disassembly of the product.
- Reduce the number of assembly operations required.
- Establish an appropriate service life for product.
- Design modular product that allows modules to be disassembly for maintenance or use.
- Decrease the number of parts involved in an assembly.
- Standardize the materials used for component assembly.
- Limit the variety of materials used in an assembly.
- Construct sub-assemblies in configurations without affecting the function of the component.
- Reduce the number of fragile parts to allow reuse and reassembly.
- Avoid the use of laminates that necessitate separation before reuse.

In alignment with the principles of the Design for Disassembly approach, this design uses modular concepts with the aim of simplifying assembly and disassembly processes. According to Tseng et al., (2018), modular design refers to structuring product design by arranging sub-assemblies and components as separate modules which can be integrated in various configurations to address diverse user needs and technical requirements.

3.3.1 The benefits of modularity

Sosale et al., (1997) in Gerhenson et al., (2003) highlight two main benefits of modular product functionality: reconfigurability and product variety. Reconfigurability allows products to be arranged and enhanced through the addition of new modules. Product variation and customization enable customers to choose from different models through the arrangement of optional modules. To integrate flexible features, it is essential to ensure that modules can be easily interchanged and reused. For optimal reusability requires designing products with separate functional modules instead of combining all functions into a single unit (one-to-one form-function mapping). Products with a modular concept offer better reusability compared to non-modular products. Successful module reusability also depends on the ease of assembly and disassembly.

Sosale et al., (1997) also discuss the impact of modularity during its life cycle. Two significant life cycle benefits and their associated design goals are as follows:

1. Maintenance: Faulty products can be easily detected and replaced by simplifying the analysis of product errors and maintenance processes.
2. Recycling, reuse, and disposal: Modular design allows components to be arranged into easily removable modules. This design approach enhances the ease of reusing, recycling, and disposing of components.

4 Result and Discussion

Design for Disassembly methodological approach, which is generally used in automotive in electronic manufacturing, presents a valuable opportunity for the furniture industry as well. This approach can be used as a sustainable strategy and an effective tool for product development and recovering disposal products and materials.

DfD techniques, which create a closed loop for a product, play an important role in reducing waste and optimizing the product manufacturing process. The implementation of the DfD method can lead to a significant reduction in production costs and provide greater flexibility during product development. This method is also essential for adapting to changing market demands and consumer preferences, which in turn leads to a cost-efficient development.

4.1 Design practice

This section describes the Design for Disassembly approach applied to furniture utilizing recycled mahogany wood waste sourced from the INPI House workshop. The project involves reusing wood pieces measuring between 10 cm by 15 cm and 15 cm by 30 cm. To be modular furniture, this product shaped as separates modules (one-to-one mapping) by combining wood pieces to create panels measuring 40 cm in height, 40 cm in width, and 3 cm in thickness.

The execution of the design process begins with 3D CAD (Computer-Aided Design) in Autodesk Fusion to precisely visualize product development, improve material selection, joint design, modular technique and specification. It allows precise measurements and adjustments to simulate how the product will perform before it is manufactured.

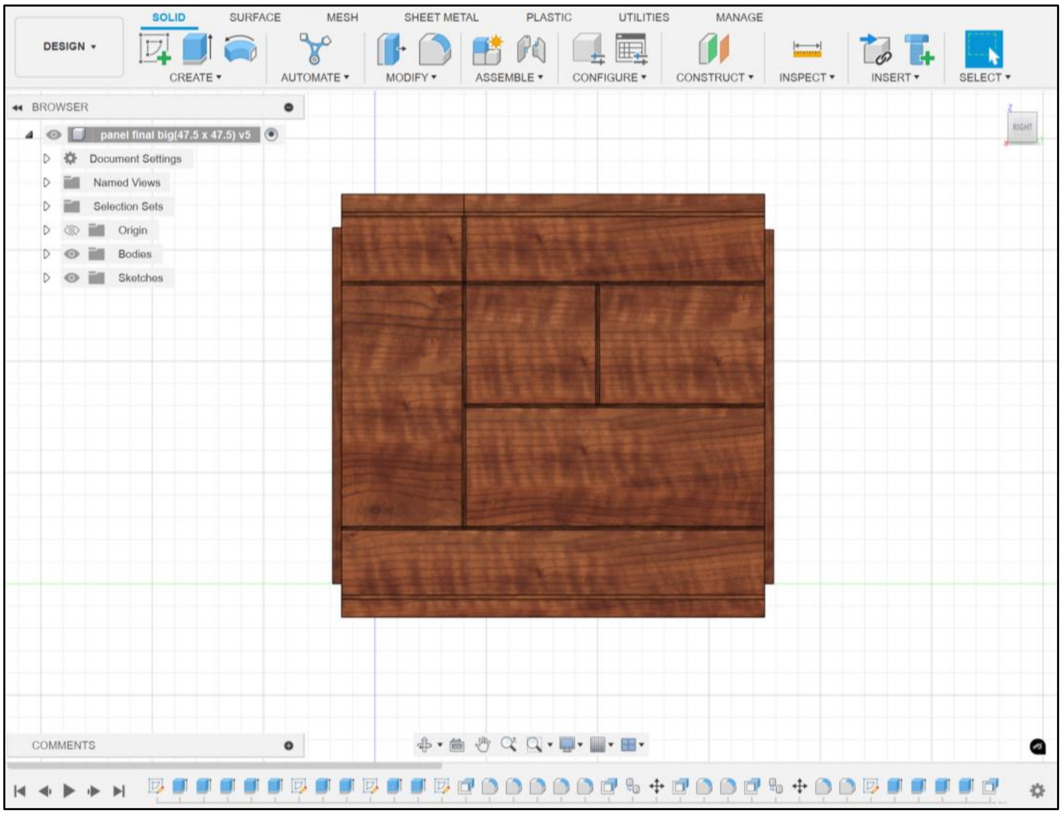

Figure 6. Wood Panel visualization in 3D CAD

Grouping modules with a dovetail joint allows easy assembly and disassembly. The dovetail joint is integrated into the panels and consists of two parts: one part features a male dovetail shape, and the other part of wood has slots that mimic the male dovetail, serving as the female joint. To allow modularity, the dovetail joint includes two male joints on one side and two female joints on the opposite side.

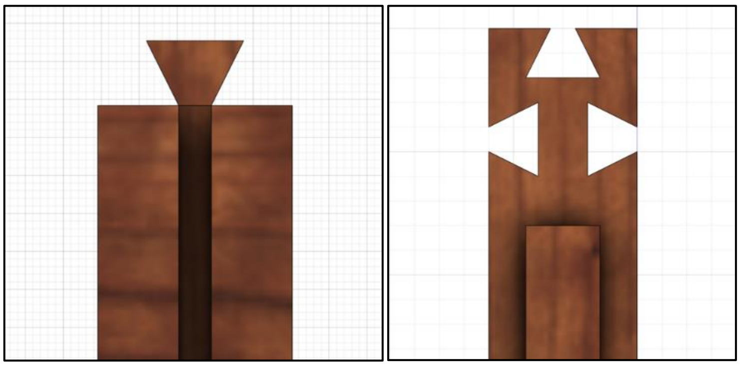

Figure 7. Male and Female Dovetail Joint

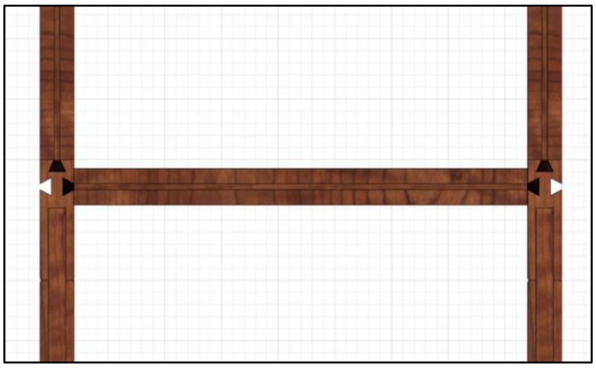

Figure. 8. Vertical and Horizontal Joint

Functioning as both horizontal and vertical connectors (Figure 8), this design allows easy assembly for connecting joints. This flexibility not only simplifies the assembly process but also allows for the configuration of modules into different shapes (Figure 9). By providing different arrangements and connections, user can customize the modules' layout to fulfil their specific needs. Whether creating a compact setup or an expansive arrangement, it is suitable for various applications and environments.

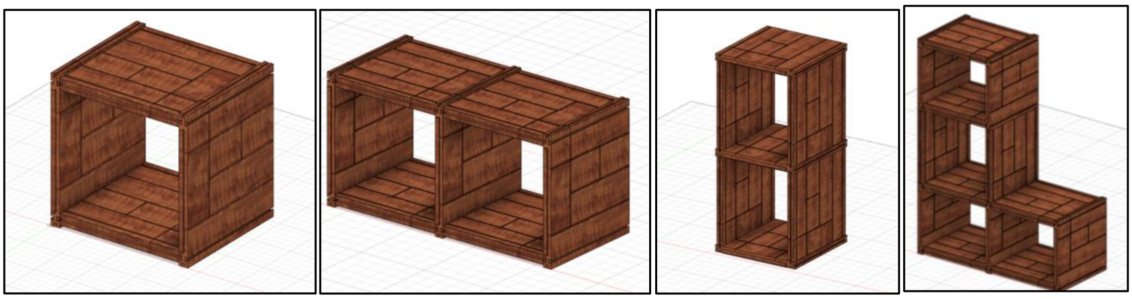

Figure 9. Module Configuration

4.2 Method Impact on Furniture Design

Implementing Design for Disassembly into the product design process allows a product and its components to be optimized for reuse and recycling once they have reached their end of life. The table presented below aims to summarize how the methods discussed in the study illustrating how they can be used as an effective tool for furniture design. This method not only decrease the demand for new materials but also contributes to a more sustainable approach to manufacturing by reducing the environmental impact. The numbers given in the table represent the impact on the effectiveness and potential benefits of these methods.

Table 2. DfD Impact on Furniture Design

DfD Principals	Applications	Reusability	Recyclability	Cost Efficiency	Manufacture Efficiency	Maintenance Efficiency
Material Selection	Mahogany Wood Waste	3	3	3	1	2
Fasteners and connectors	Integrated Dovetail Joint	3	1	3	1	1
Product Structure and Component Design	Modular Concept	3	3	3	1	3

1 = Poor impact 2 = Good impact 3 = Big impact

When a product is designed with disassembly, it becomes significantly easier to repair and maintain, resulting longer product life. Ease of maintenance not only benefits consumers by providing longer-lasting products but also promotes a more sustainable approach. By facilitating repairs and reuse, Design for Disassembly contributes to a reduction in the environmental footprint of the furniture industry and opens a way to a more sustainable industry.

5 Conclusion

- Design for Disassembly is a method that focuses on creating products that makes them easy to disassemble. The goal of DfD is to enhance resource efficiency and manufacturing sustainability.
- The primary aim of this paper is to support the current and future development in the area of disassembly.
- Design decisions concerning materials and connection methods directly influence the product structure and component design.
- Not every aspect of DfD principles can be applied to every design. Each principle may present challenges that require a flexible solution, e.g. the production of furniture modules that require to use wood adhesive.
- Implementing DfD in furniture optimizes products for reuse and recycling at the end of their life cycle.
- It is beneficial to limit the number of components and component types used in the design process. Simplifying the assembly and disassembly of furniture enhances the efficiency and ease of recycling.
- This approach significantly reduces the demand for new raw materials, promoting a more sustainable use of resources.
- Using this method can lead to lower production costs and increased efficiency, benefiting manufacturers financially.

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Author Contributions

Nurnajman Assyiraq Ibrahim: Conceptualization, Data Curation, Formal Analysis, Resources, Investigation, Methodology, Validation, Visualization, Writing - original draft, **Sheila Andita Putri:** Methodology, Project Administration, Supervision, Validation, Writing – original draft, Writing – review and editing.

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Mobilya ve Ahşap Malzeme Araştırmaları Dergisi
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Kavak kaplamadan üretilen tabakalı kaplama kerestenin mekanik özellikleri üzerine rutubet içeriğinin etkisinin değerlendirilmesi

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ÖZ: Özellikle son yıllarda meydana gelen depremlerden sonra, ahşap yapılara karşı ilgi artmıştır. Ancak, ahşap yapılarda yük taşıyan ahşap esaslı elemanların çürümeye, yangına ve rutubete karşı dayanımı bu ilgiyi etkilemektedir. Bu çalışmada, kavak ağacından elde edilen soyma kaplama ile tabakalı kaplama kereste (TKK) üretilmiş ve malzemenin bazı mekanik özellikleri farklı rutubet içeriklerinde incelenmiştir. TKK üretiminde Fenol Formaldehit (FF) tutkalı kullanılmıştır. Üretilen malzeme 5 farklı rutubet içeriğine şartlandırılmıştır, ardından çeşitli mekanik testlere tabi tutulmuştur. Bu amaç için, üretilen malzemenin bazı fiziksel özelikleri (tam kuru yoğunluk ve rutubet yüzdesi) ve mekanik özellikleri (eğilme direnci, eğilmede elastikiyet modülü, eğilmede deformasyon, sertlik, vida tutma kapasitesi, çekme-makaslama direnci) belirlenmiştir. Yapılan testler sonunda elde edilen bulgulara göre; TKK'nın rutubet içeriği arttıkça, eğilme direnci, elastikiyet modülü, sertlik değeri ve vida tutma kapasitesi azalmış, buna karşı, eğilmede deformasyon değeri artış göstermiştir. Çekme-makaslama direnci testi ile rutubet içeriği arasında doğrusal bir ilişki tespit edilememiştir.

Anahtar kelimeler: Ahşap Malzeme, TKK, Kavak kaplama, Rutubet, Mekanik özellikler

Evaluation of the effect of moisture content on the mechanical properties of laminated veneer lumber produced from poplar veneer

ABSTRACT: In recent years, particularly following major earthquakes, interest in wooden structures has increased. However, the performance of the load-bearing wood-based elements in wooden structures against decay, fire, and moisture affects this interest. In this study, laminated veneer lumber (LVL) was produced with rotary cut veneer obtained from poplar wood, and some mechanical properties of the material were examined at different moisture contents. Phenol Formaldehyde (FF) glue was used in the production of LVL. The produced material was conditioned to 5 different moisture contents and then subjected to various mechanical tests. For this purpose, some physical properties (oven- dried density and moisture percentage) and mechanical properties (bending strength, modulus of elasticity in bending, deformation in bending, hardness, screw holding capacity, tensile-shear resistance) of the produced material were determined. The test results showed that; as the moisture content of the LVL increased, the bending strength, elastic modulus, hardness value and screw holding capacity decreased, whereas the deformation value in bending increased. No linear relationship was found between the tensile-shear strength test and moisture content.

Keywords: Wood Material, LVL, Poplar veneer, Moisture content, Mechanical properties

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1 Giriş

Ahşap, tarih boyunca inşaat ve mühendislik alanlarında önemli bir malzeme olmuştur ve modern çağda da sürdürülebilirlik anlayışının artmasıyla bu özelliğini sürdürmektedir. Doğal bir malzeme olarak ahşap, çevre dostu, yenilenebilir, kolay işlenebilen, estetik bir görünüme sahip olan olması, yüksek direnç-yoğunluk oranına sahip olması ve biyolojik olarak doğada kolay bozunabilir özelliklere sahip olup, bu özellikleri sayesinde inşaat sektöründe büyük bir ilgi görmektedir (Bozkurt ve Erdin, 1997; Bal, 2016a). Ancak, doğal ahşabın, bir yapı malzemesi olarak kullanılmasında, bazı istenmeyen özellikleri de bulunmaktadır. Kolay çürümesi, doğal olarak ölçülerinin sınırlı olması, kendinden kaynaklanan büyüme kusurları barındırması, budak olan bölgelerinde mekanik dayanımının düşük olması, higroskopik bir malzeme olması nedeniyle bulunduğu ortama göre rutubet alması veya vermesi, rutubet içeriğindeki değişimlerin hacmen ölçüsünü ve ayrıca mekanik performansını değiştirmesi gibi istenmeyen özellikleri de bulunmaktadır (Bozkurt ve Erdin, 1997; Örs ve Keskin, 2001).

Masif ahşap malzemenin istenmeyen özelliklerinin bertaraf edilebilmesi için çeşitli yöntemler ile masif ağaç malzemeden, yonga levha, lif levha, kontrplak, tutkallanmış tabakalı kereste, çapraz tabakalı kereste, tabakalı kaplama kereste (TKK), yönlendirilmiş şerit kereste ve lamine şerit kereste gibi mühendislik ürünü ağaç malzemeler geliştirilmiştir. Bu son üç malzeme, aynı zamanda yapısal kompozit keresteler grubunun üyeleri olarak sınıflandırılmaktadır (Nelson, 1997; Güler, 2001; Berlung ve Rowell, 2005; Stark ve Cai, 2021). Yapısal kompozit keresteler, masif ağaç malzemeye göre; daha büyük ölçülerde üretilebilmesi, kusurlarından arındırılmış olması, çürümeye karşı daha dayanıklı olması, büyüme gerilmesi taşımaması gibi, masif ahşaba göre üstün mekanik özellikleri nedeniyle tercih edilmektedir (Bal, 2021). Yapısal kompozit kerestelerin en önemli üyesi TKK'dır. TKK, yumuşak ağaç türlerinden ve düşük-orta yoğunluklu (290-690 kg/m^3) ağaç türlerinden üretilmektedir (Bal, 2016b; Ozarska, 1999).

TKK malzemenin mekanik özellikleri üzerine birçok çalışma gerçekleştirilmiştir. Farklı ağaç türlerinden üretilen TKK malzemenin eğilme özellikleri ile yapışma performansı üzerine (Carvalho ve ark., 2004; Aydın ve ark., 2004; Saviana ve ark., 2009; Kılıç 2011; Bal ve Bektaş, 2012a; Bal, 2016a), dinamik eğilme direnci üzerine araştırmalar yapılmıştır (Janowiak and Bukowski, 2000; Bao ve ark., 2001; Çolak ve ark., 2007; Bal, 2016b). Ayrıca, TKK malzemenin mekanik özellikleri üzerine güçlendirme (Perçin ve Uzun, 2023; Atar ve Mengeloğlu, 2024) ve ısıl işlemin etkileri de araştırılmıştır (Perçin ve Uzun, 2023; Perçin ve Ülker, 2023; Çiğdem ve Perçin, 2023; Perçin, 2023).

TKK üretiminde kullanılan soyma kaplama levhaları doğal özellikleri levha üretim süreçlerinde fazla değiştirilmediği için elde edilen TKK malzeme masif ağaç malzemeye yakın özellikler sergiler. Masif ağaç malzemenin; teğet, radyal ve enine yüzeylerinde ve bu yönlerdeki özellikleri yüzeye göre nasıl değişiyorsa, bu üç temel yönde TKK malzemenin özellikleri de değişiklik göstermektedir. Bu nedenle, TKK malzeme üzerinde yapılan bilimsel çalışmalarda TKK malzemenin kuvvet uygulanan yüzeye göre özellikleri araştırılmıştır (Carvalho ve ark., 2004; Bal, 2012a,b; Kılıç, 2011; Kurt ve Çil, 2012). Bazı çalışmalarda ise, TKK malzemenin sıcak preste üretilmesi esnasında pres parametrelerin üretilen malzemenin fiziksel ve mekanik bazı özellikleri üzerine etkisi araştırılmıştır (Shukla ve Kamdem, 2008; Kurt ve ark., 2011). Diğer bazı çalışmalarda ise, TKK malzemenin üretiminde kullanılan tutkalın, üretilen malzemenin; fiziksel, mekanik veya diğer teknolojik özellikleri üzerine etkisi araştırılmıştır (Shukla ve Kamdem, 2009; Bal ve Bektaş, 2012a,b; Atar ve Mengeloğlu, 2024).

TKK malzeme üzerine yapılan önceki çalışmalarda, birçok farklı faktörün, TKK malzemenin yanma özellikleri, fiziksel özellikleri ve mekanik özellikleri üzerine etkileri araştırılmıştır. Ancak, yazarların ulaşabildiği kadarıyla, kavak soyma kaplamaları ve fenol formaldehit tutkalı ile üretilen TKK malzemenin mekanik özellikleri üzerine rutubet içeriğinin etkisi araştırılmamıştır. Bu noktadan hareketle, bu çalışmanın amacı; rutubet içeriğinin TKK malzemenin mekanik özellikleri üzerine etkisinin araştırılmasıdır.

2 Materyal ve Metot

2.1 Materyal

2.1.1 Soyma kaplamalar

Bu çalışmada, kavak (*Populus sps*.) tomruklarından soyma yöntemi ile elde edilen 2.7 mm kalınlıktaki soyma kaplamalar kullanılmıştır. Çalışmada kavak soyma kaplamaların kullanılma sebepleri; buharlama yapılmadan soyma yapılabilmesi, maliyetinin diğer ağaç türlerine göre düşük olması ve kontrplak sektöründe fazla kullanılan ağaç türlerinden olmasıdır.

Soyma kaplamalar, özel bir kontrplak fabrikasından satın alma yolu ile temin edilmiştir. Temin edilen soyma kaplamalar öncelikle çalışma ortamına nakledilmiş ve sonra 30 x 30 cm (genişlik x uzunluk) ölçülerinde ebatlanmıştır. Bu haliyle TKK levha üretimine hazır hale getirilmiştir. Sonra oda şartlarında kondisyonlanmıştır. Kaplamaların kusurlu, çürük, budaklı olanları TKK üretiminde kullanılmamıştır. TKK üretiminde kullanılmadan önce gevşek yüz-sıkı yüz işaretlemesi yapılmıştır. TKK levhaları üretilirken tutkal gevşek yüzeye sürülmüştür.

2.1.2 Tutkal

Bu çalışmada, tutkal olarak fenol formaldehit tutkalı kullanılmıştır. Suya ve çözücülere karşı son derece dayanıklı (D4 grubu) olması, iyi yapışma direnci göstermesi, kolay uygulanabilmesi, düşük viskozite göstermesi ve endüstriyel olarak üretilen TKK levhaların üretiminde bu tutkal kullanılması nedeniyle, çalışmada bu tutkal tercih edilmiştir. Tutkal, özel bir tutkal üreticisi firmadan temin edilmiştir. Tutkal içerisine hiçbir dolgu veya katkı maddesi katılmamıştır. Tutkal seyreltilmeden kullanılmıştır. Tutkal bekletilmeden ve taze halde kullanılmıştır. Tutkal içerisine kürleşmeyi hızlandırmak için hiçbir madde eklenmemiştir.

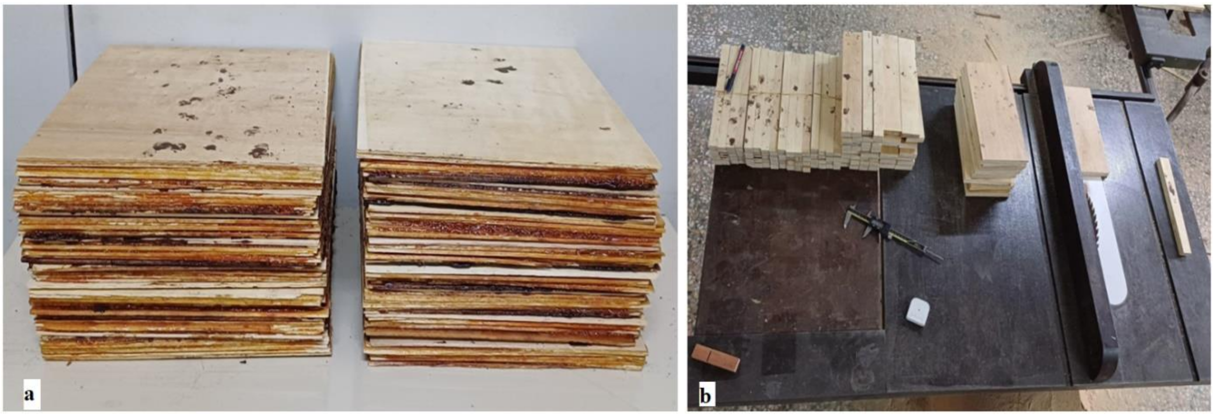
2.1.3 Levhaların üretilmesi

Kaplama levhaları, öncelikle 30 x 30 cm (genişlik x uzunluk) ölçülerinde ebatlanmıştır. Daha sonra, her bir kaplama levhasının gevşek yüzeyi belirlenmiş ve işaretlenmiştir. Her bir TKK levhasının üretilmesinde 8 kaplama levhası kullanılmıştır. Bu 8 kaplamasının ilk dört tanesi gevşek yüzeyleri levhanın orta tabakasına doğru diğer 4 levha ise test yönde ve yine gevşek yüzeyleri levhanın ortasına doğru, tutkallandıktan sonra, yerleştirilmiştir Bu şekilde yaparak, elde edilen levhaların tam olarak simetrik olması amaçlanmıştır. Ayrıca, levhanın alt ve üst yüzeylerindeki kaplamaların sıkı yüzeyleri dış tarafa bakacak şekilde yerleşim sağlanmıştır.

Kaplama levhalarına tutkal bir fırça ile sürülmüştür. Tutkal ortalama olarak 180±10 g/m^2 olarak uygulanmıştır. Tutkal kaplama levhalarının gevşek yüzeylerine sürülmüştür. Kaplamalar tutkallandıktan sonra levha taslağı 2 adet pres sacı arasına bırakılıp sıcak prese yerleştirilmiştir. Sıcak preste levha toplam 20 dakika süre ile 180 ^{o}C sıcaklıkta (pres plaka sıcaklığı) preslenmiştir. Preste toplam 5 ton (5.5 kg/cm^2) basınç uygulanmıştır. Pres süresi sonunda levha presten çıkarılmış ve üst üste bırakılıp 1 hafta süre ile bekletilmiştir (Şekil 1-a). Denemelerde toplam 16 levha üretilmiştir.

2.1.4 Test örneklerinin hazırlanması

Levhalar üretildikten sonra, her bir levhanın kenar kısımları öncelikle temizlenmiş ve daire testerede kesilerek net ölçülere getirilmiştir. Daha sonra, her bir levhadan, her bir test için 1 adet test örneği kesilmiştir. Böylece, her bir deney grubu için 16 adet, 5 deney grubu için toplam 80 adet test örneği kesilmiştir (Şekil 1-b).



Şekil 1. Üretilen levhaların presleme sonrası görüntüsü (a), test örneklerinin hazırlanması (b)

Her test örneği üzerine test grubu ve örnek numarası yazılmıştır. Daha sonra, test örneklerinin tamamı etüvde kurutulmuş ve tam kuru ağırlıkları kaydedilmiştir. Böylece, deney gruplarının %0, %10, %20, %40 ve %130 şeklinde 5 farklı rutubetteki ağırlıklarının ne olacağı hesaplanma ile belirlenmiştir. Çalışmada deneme grupları ve rutubet içerikleri Tablo 1'de verilmiştir.

Tablo 1. Deneme grupları, rutubet yüzdeleri ve tahmini rutubet sapmaları

Grup No	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
Rutubet yüzdesi	%0+1	%10±1	%20±2	%40±5	%130±10

2.1.5 Test örneklerinin rutubetlerinin ayarlanması

Çalışmada, TKK test örneklerinin farklı rutubet seviyelerinde, mekanik özelliklerinde meydana gelen değişmelerin belirlenmesi amaçlanmıştır. Bu amaç için 5 farklı rutubet seviyesinde deney grupları oluşturulmuştur. Deney gruplarından grup 1 (%0) test örnekleri, etüvde kurutularak tam kuru (%0) rutubet haline getirilmiştir. Grup 2 (%10) test örnekleri ise, oda şartlarında bekletilerek kondisyonlanmış ve %10±1 rutubet seviyesine getirilmiştir. Grup 3 (%20±2) test örnekleri ise, test örnekleri üzerine su spreyi sıkılmış ve tahmini ağırlığa geldiklerinde, bu ağırlık ile plastik poşet içerisine bırakılmış, bu halde 1 hafta bekletilmiş ve yüzeydeki rutubetin test örnekleri iç kısımlarına difüzyon yoluyla dağılması sağlanmaya çalışılmıştır. Grup 4 (%40±5) test örnekleri ise, su dolu bir kap içerisine batırılmış ve çıkarılınca ağırlığı tartılmıştır. Hedeflenen ağırlığa geldiğinde, bir poşet içerisine bırakılmış, bu halde 1 hafta bekletilmiş ve bünyesine aldığı suyun iç kısımlara difüzyon yoluyla dağılması sağlanmaya çalışılmıştır. Grup 5 (%130±10) test örnekleri ise, su dolu bir kap içerisine batırılmış ve yaklaşık 1 hafta süre ile su içerisinde batık vaziyette bekletilmiştir. Sonra sudan çıkarılan test örneklerinin ağırlığı ölçülmüş ve bu süre sonunda ki rutubetleri hesaplanmıştır. Bu hesaplanan rutubet yüzdeleri ise ilgili çizelgelerde verilmiştir.

2.2 Metot

TKK test örneklerinin yoğunluk testi TS EN 323 (1999) numaralı standartta belirtilen esaslara göre yapılmıştır. Testler için, 20x50x50 mm (kalınlık x genişlik x uzunluk) ölçülerine sahip, her grup için 16 adet ve toplamda 80 adet numune hazırlanmıştır. Bu hazırlanan numunelerin en, boy ve yükseklikleri ±0,01 mm duyarlılıkta dijital kumpas yardımı ile ölçüldükten sonra hava kurusu ağırlıkları 0,01 gr duyarlılıklı hassas terazi yardımı ile belirlenmiştir. Yoğunluk tayini, hassas terazide ölçülen ağırlığın, kumpasla ölçülen hacme bölünmesi ile hesaplanmıştır.

TKK test örneklerinin rutubet tayini TS EN 322 (1999) standardında belirtilen esaslara göre yapılmıştır. Rutubet tayini eğilme direnci test örnekleri üzerinde yapılmıştır. İlk olarak test örnekleri, etüvde 105 °C'de değişmez ağırlığa ulaşıncaya kadar kurutulmuş ve hassas terazi ile tartılmıştır. Sonra test örnekleri rutubetli hale getirilmiş ve rutubetli ağırlıkları 0,01 gr duyarlı hassas terazide tartılmıştır. Rutubet yüzdesi, test örneğinin rutubetli haldeki ağırlığı ile tam kuru haldeki ağırlığı arasındaki farkın, tam kuru ağırlığa bölünmesi ile belirlenmiştir. Rutubet içeriği yüzde olarak gösterilmiştir.

Çalışma kapsamında üretilen TKK'lardan eğilme testi test örnekleri hazırlanmıştır. TKK test örnekleri TS EN 310 standardına uygun olarak 3 nokta eğilme direnci testine tabi tutulmuştur. Her grup için 16 adet test örneği 20x20x300 mm boyutlarında hazırlanmıştır. Eğilme direnci için test hızı 5 mm/dk, ön yük 10 N, mesnet arası mesafe 240 mm olarak ayarlanmıştır. Elastikiyet modülü, elastik bölgede, maksimum yükün %10 ile %40'ın karşılık gelen sehim noktalarına göre hesaplanmıştır.

Tabakalı kaplama kereste test örnekleri üzerinde vida tutma kapasitesi testi yapılmıştır. Bu test için TS EN 13446 standardına uygun olarak anma ölçüsü 20x50x50 mm (kalınlık x genişlik x uzunluk) ebatlarında, her grup için 16 adet ve toplamda ise 80 adet test örneği hazırlanmıştır. Vida tutma deneyi için vidanın batma miktarı ve açısı çok önemlidir. Numuneler hazırlanırken vidaların aynı miktarda takılmasına ve 90° açı olmasına özen gösterilmiştir. Kullanılan vida çapı 4 mm olup batma miktarı 20 mm'dir. Test hızı 5 mm/dk ve ön yük 20 N olarak belirlenmiştir.

Tabakalı kaplama kerestenin çekme-makaslama direncinin belirlenmesinde TS 3969 EN 314-1 (1998) ve TS 3969 EN 314-2 (1999) numaralı standartlarda belirtilen esaslara uyulmuştur. Bu standartlara göre deney parçalarının hazırlanması, deneyin yapılışı, hesaplama ve sonuçların gösterilmesi sırasıyla ve kısaca şu şekildedir; her bir deney parçası, yüzeydeki tabakanın elyafı yönünde kesilmiş ve ölçüleri; biçme uzunluğu L1: 25±5 mm, Biçme eni b1: 25±5 mm, Testere kesiğinin eni b2: 2,5 - 4 mm kelepçelerin uzaklığı L2: 50 mm olarak ayarlanmıştır. Deney örnekleri, ait oldukları grupların nem içeriğine ulaştıktan sonra test edilmiştir. Çekme-makaslama direnci testi sonrasında, test örneklerinin kopma yüzeylerinde odun kırılması ve tutkal kırılması incelenmiştir.

Test örneklerinin sertlik değeri TS 2479 numaralı (1976) standarda göre belirlenmiştir. Bu standarda göre; test örneği, kenarları 20x50x50 mm ölçülerinde hazırlanmıştır. Denemeler sadece teğet yüzeyde (üst yüzey) yapılmıştır. 5 mm/dk hızla hareket eden yükleme ucu ile deney parçasının teğet kesit yüzeylerinin merkez eksenleri üzerinde yarım küre ucun yarıçapına (5.64 mm) eşit olan derinlikte bir oyuk açılmıştır. Bu derinliğe ulaşıldığı andaki yük kaydedilmiştir. Her bir deney parçasının statik sertliği, deneyin yapıldığı rutubet miktarında, alanı 100 mm^2'ye eşit olan ve 5.64 mm derinlikte bir iz elde edebilmek için, gerekli yük miktarı N türünden elde edilen maksimum kuvvetin 100 mm^2 alana bölünmesi ile hesaplanmıştır. Test sonucu N/mm^2 olarak gösterilmiştir.

3 Bulgular ve Tartışma

Denemelerde kullanılan fiziksel test örneklerinin tam kuru yoğunlukları hesaplanmış ve Tablo 2'de verilmiştir. Bu tablo incelendiğinde, gruplara ait test örneklerinin ortalama tam kuru yoğunluk değerlerinin 401 ile 411 kg/m^3 arasında değiştiği tespit edilmiştir. Grupların tam kuru yoğunluk değerleri arasında, çok büyük farklılıklar yoktur. Bu durum, grupların homojen gruplar olduğunun bir göstergesidir. Yapılan bu çalışmada, tabakalı kaplama kereste malzemenin, mekanik özellikleri üzerine rutubetin etkisi araştırılmıştır. Yoğunluğun etkisi, bu çalışma kapsamı dışındadır. Bu nedenle, gruplar arasında yoğunluk farklılığının olmaması çalışmadan elde edilen diğer verilerin güvenilirliği bakımından da önem arz etmektedir. Grupların tam kuru yoğunluk değerleri arasında istatistiksel olarak bir farklılığın olup olmadığı yapılan ANOVA testi ile belirlenmiştir. Gruplar arasındaki farklılığın istatistiksel olarak önemsiz (NS) olduğu ve önem seviyesi değerinin (P) 0.05'den büyük olduğu (P> 0.05) belirlenmiştir. Aslında, Tablo 2'deki verilere göre; gruplar arasında küçük farklılıklar vardır, ancak, bu farklılıklar istatistiksel olarak önemsizdir. Yapılan önceki çalışmalarda, TKK'nın yoğunluğunun, mekanik özelliklerini etkilediği, yoğunluğu yüksek olan TKK malzemeden daha yüksek mekanik özellikler elde edildiği bildirilmiştir (Bal, 2016a; Bal ve Bektaş, 2012a,b).

Tablo 2. Test gruplarının ortalama tam kuru yoğunluk değerleri (İlker 2025)

İstatistik değerler	Gruplar				
	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
x̄	410.8	401.7	409.0	404.0	411.4
ss	30.9	28.9	30.4	29.8	18.1

Laboratuvar çalışmaları esnasında, her mekanik özellik için her gruba ait test örneklerinin rutubetleri, mekanik testler yapıldıktan sonra test örneğinin rutubet yüzdesi hesaplanmıştır. Elde edilen veriler Tablo 3'te verilmiştir. Tabloda verilen rutubet yüzdeleri incelendiğinde, çalışma planlanırken hedeflenen rutubet yüzdelerine genel olarak ulaşıldığı görülebilir. Bu çalışmada, 5 farklı rutubet içeriğinin tabakalı kaplama kerestenin mekanik özellikleri üzerine etkisinin araştırılması planlanmıştır. Çalışmada grup 1 (%0) rutubet içeriğine pratikte ulaşmak elbette zordur. Uzun süre kurutulsa dahi ahşap malzemede %0 rutubete ulaşılması çok zordur. Ancak, bu çalışmada %1'in altındaki rutubet içeriğinde, tabakalı kaplama kerestenin mekanik özellikleri ile diğer gruplar arasındaki farkı görebilmek amacıyla grup 1 deneme grupları içerisine dahil edilmiştir.

Tablo 3. Test örneklerinin rutubet yüzdeleri (İlker, 2025)

		Gruplar (%)				
Mekanik özellikler	İstatistik değerler	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
Eğilme direnci test örnekleri	x̄	**0.22**	**11.59**	**20.64**	**40.11**	**129.32**
	ss	0.06	0.95	1.72	3.64	10.86
Vida tutma direnci test örnekleri	x̄	**0.42**	**11.95**	**20.54**	**40.05**	**138.44**
	ss	0.14	0.63	2.3	4.13	12.924
Janka sertlik test örnekleri	x̄	**0.37**	**11.78**	**21.14**	**38.42**	**134.88**
	ss	0.1	0.54	3.07	6.28	10.19
Yapışma direnci test örnekleri	x̄	**0.42**	**10.88**	**21.68**	**38.52**	**135.2**
	ss	0.06	0.44	1.77	3.61	7.7

x̄: aritmetik ortalama, ss: standart sapma

TKK test örneklerinin eğilme testleri yapılmış ve elde edilen eğilme direnci testi bulguları Tablo 4'te verilmiştir. Bu tablo incelendiğinde, test örneklerinin eğilme direnci değerleri 31.5 ile 68.8 N/mm^2 aralığında ölçüldüğü görülebilir. En büyük eğilme direnci değeri grup 1'de ve en küçük eğilme direnci ise grup 5'te ölçülmüştür. Test örneğinin rutubet içeriği arttıkça eğilme direnci değeri de azalmıştır. Tabakalı kaplama kereste, masif ağaç malzeme ve ahşap esaslı diğer malzemelerde de rutubet içeriği eğilme direncini etkilemektedir. Bu konuda önceki çalışmalarda benzer sonuçlar rapor edilmiştir (Bozkurt Erdin, 1997; Örs ve Keskin, 2001). Masif ağaç malzemenin, eğilme direncinin belirlenmesinde kullanılan TS 2474 (1976)'de standardında da rutubetin eğilme direnci üzerine etkisi belirtilmiş ve masif ağaç malzemenin rutubetinin %9 ile %15 aralığın da bulunması halinde, rutubetteki her bir %1'lik artışın, masif ağaç malzemenin eğilme direncinde %4'lük azalmaya sebep olacağı bildirilmiştir. Grupların birbirlerinden istatistiksel olarak önemli derecede ($P<0.001$) farklı olduğu, yapılan ANOVA testi sonuçlarına göre belirlenmiştir.

Tablo 4. Eğilme direnci testine ait bulgular (N/mm^2) ve Duncan testi sonuçları (İlker 2025)

Eğilme direnci	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
x̄	**68.78 A**	**60.31 B**	**57.18 B**	**48.43 C**	**31.58 D**
ss	10.04	8.69	6.60	5.91	3.21

Tabakalı kaplama kerestenin eğilme testi esnasında elde edilen verilerle, her bir test örneğinin yük-deformasyon eğrisinde, maksimum kuvvetin %10 ve %40 noktalarında ölçülen yük-sehim miktarları ile elastikiyet modülü belirlenmiştir. Elde edilen veriler Tablo 5'de verilmiştir. Bu çizelge incelendiğinde, grupların elastikiyet modülü değerlerinin 2326 ile 6044 N/mm^2 aralığında sıralandığı görülebilir. Ayrıca, yapılan Duncan testi sonucuna göre; gruplar arasından fark vardır. Denemeler sonunda elde edilen veriler ile gruplar arasında farklılık olup olmadığını belirlemek için tek faktörlü ANOVA testi yapılmış ve gruplar arasında istatistiksel olarak ileri düzeyde önemli ($P<0.001$) farklılık olduğu belirlenmiştir.

Tablo 5. Elastikiyet modülü testine ait bulgular (N/mm^2) ve Duncan testi sonuçları (İlker 2025)

Elastikiyet modülü	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
x̄	**6044 A**	**3084 B**	**2741 C**	**2486 D**	**2326 D**
ss	720	476	450	322	248

Tabakalı kaplama kerestenin eğilme testi esnasında elde edilen verilerle, eğilmede deformasyon miktarları da belirlenmiştir. Bu bulgular Tablo 6'da verilmiştir. Bu bulgular incelendiğinde, en küçük deformasyon değerinin grup 1'de ve en büyük deformasyon değerinin ise grup 5'de ölçüldüğü görülebilir. Gruplar arasındaki farklar, Duncan testi sonuçlarına göre önemlidir. Bu testten elde edilen bulgular diğer mekanik özelliklere göre genel eğilim olarak aksi yönde gerçekleşmiştir. Diğer mekanik özellikler, grupların rutubet içeriği arttıkça azalma göstermiş ancak eğilmede deformasyon değeri ise artış göstermiştir. Aslında bu durum, test örneğinin rutubet içeriği arttıkça, eğilme kuvvetine karşı malzemenin kırılmadan tek parça olarak kalabilme kabiliyetini göstermektedir. Aşağıda verilen grafiklere göre; yük-deformasyon grafiği altında kalan alan ne kadar büyükse malzeme o kadar sünek bir malzemedir. Bu bilgiye göre grup 5 test örnekleri diğer gruplara daha sünektir. Eğilmede deformasyon miktarına ait bulgular arasında fark olup-olmadığını gösteren ANOVA testine göre, gruplar arasında istatistiksel olarak çok ileri düzeyde ($P<0.001$) fark olduğu tespit edilmiştir.

Tablo 6. Eğilmede deformasyon (mm) değerine ait bulgular ve Duncan testi (İlker 2025)

Eğilmede Deformasyon	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
x̄	**6.2 E**	**11.8 D**	**13.9 C**	**16.5 B**	**22.3 A**
ss	0.7	1.6	1.6	2.8	4.1

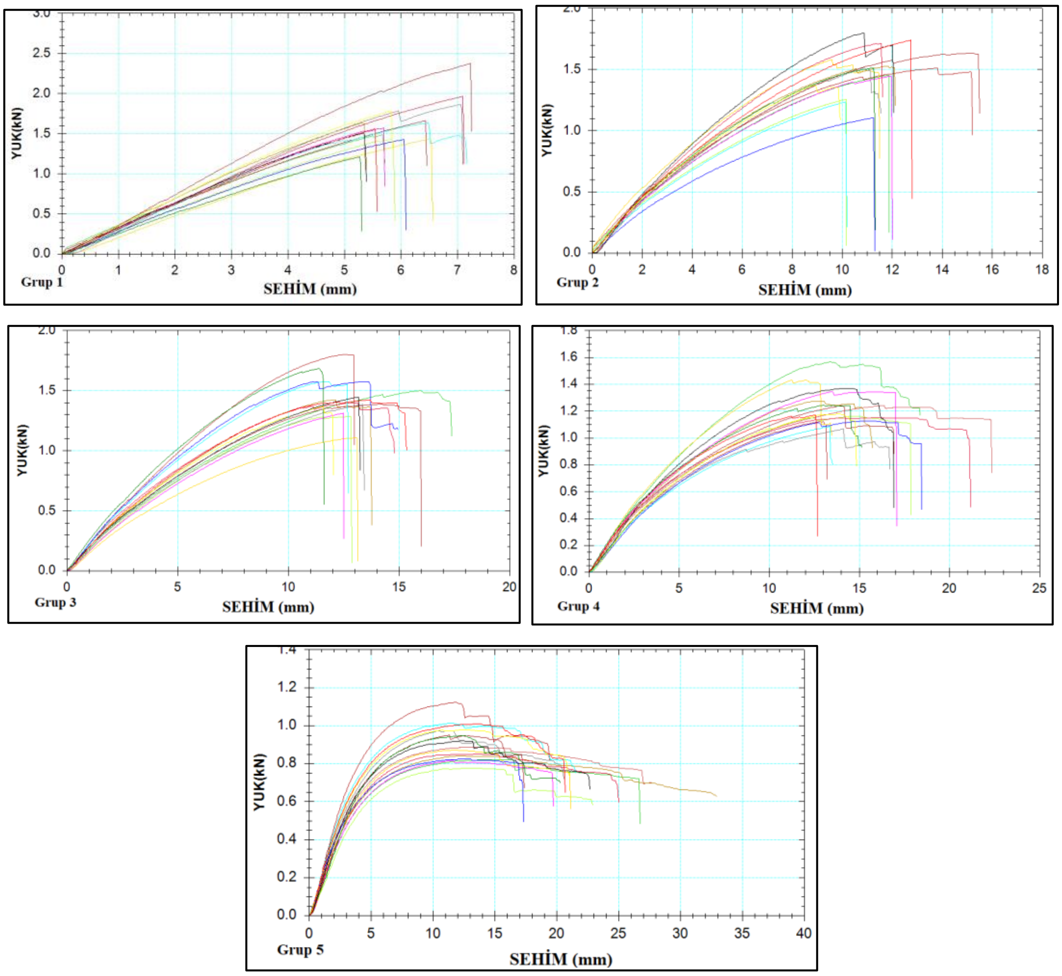
Eğilme direnci testleri esnasında elde edilen yük-sehim verileri ile yük-sehim grafikleri oluşturulmuş ve Şekil 2'te verilmiştir. Bu grafikler incelendiğinde, eğilme testleri esnasında, test örneğinin rutubeti arttıkça, (grup 1'den grup 5'e doğru) eğilme testinde test örneğinin daha uzun süre kırılmadan yüke karşı koyabildiği görülebilir. Ancak, bunun zıttı olarak rutubet miktarı azaldıkça, ahşap malzemenin eğilme yüküne maruz kaldığında kırılma gerçekleşmeden önce çok az bir deformasyona dayanabildiği görülebilir. Şekil 2'te verilen grafikler incelendiğinde, ayrıca, grupların rutubet içerikleri arttığında test örneğinin taşıyabildiği maksimum yük miktarının da azaldığı görülebilir. Örneğin, grup 1'de test örneklerinin taşıyabildiği maksimum yük miktarı 1-2.4 kN aralığında değişirken, grup 5'de bu yük değeri 0.8 ile 1.1 kN aralığına kadar düşmüştür. Masif ahşap malzeme veya ahşap esaslı kompozit malzemeler konusunda yapılan önceki çalışmalarda da benzer sonuçlar rapor edilmiştir (Bozkurt ve Erdin, 1997; Örs ve Keskin, 2001; Hıdır ve ark., 2024).

Test örneklerinin çekme-makaslama (yapışma) testine ait veriler, Tablo 7'de verilmiştir. Bu veriler incelendiğinde, gruplar arasında farkların çok küçük olduğu ve bazı grupların aralarında fark olmadığı belirlenmiştir. Bu durum diğer mekanik özelliklerden farklı olan bir sonuçtur. Bu mekanik testte bu şekilde sonuç elde edilmesinin nedeninin, çekme-makaslama testine etki eden faktörler sadece odun özellikleri değil aynı zamanda tutkalın yapışma performansıdır. Yapılan görsel muayenede, bu test esnasında test örneklerinin bazılarında tutkal hattının bir kısmında ayrılma olduğu görülmüştür. Bu durumda, elde edilen verilerin sadece rutubetin odun üzerine etkisi ile meydana geldiğini söylemek mümkün değildir. Aynı zamanda tutkal yapışması da etkilenmiştir. Gruplar arasında çekme-makaslama testi verilerine göre anlamlı bir fark olup olmadığı ANOVA testi ile araştırılmış ve bir fark olmadığı (NS) tespit edilmiştir.

Tablo 7. Çekme-makaslama direnci testine ait veriler ve Duncan testi sonuçları

Çekme-makaslama Direnci	Gruplar (N/mm^2)				
İstatistik değerler	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
x̄	**3.3 A**	**3.6 A**	**3.6 A**	**3.3 A**	**3.3 A**
ss	0.6	0.7	0.4	0.4	0.4

Laboratuvar denemelerinde, test örneklerinin statik sertlik testi sonunda elde edilen bulgular Tablo 8'de sunulmuştur. Tablo incelendiğinde, statik sertlik değerlerinin test örneklerinin rutubet içeriği arttıkça azaldığı tespit edilmiştir. Duncan testine göre tüm gruplar arasındaki (grup 4 ile grup 5 hariç) farklar anlamlıdır. Statik sertlik testi bulgularına göre, test grupları arasında anlamlı bir farklılık olup olmadığını belirlemek için ANOVA testi yapılmış sonuçlara göre, gruplar arasında istatistiksel olarak ileri düzeyde ($P<0.001$) farklılıklar olduğu tespit edilmiştir.



Şekil 2. Test örneklerinin yük-sehim grafikleri (tüm gruplar)

Tablo 8. Statik sertlik testi verileri ve Duncan testi sonuçları (İlker, 2025)

Sertlik testi (N/mm^2)	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
x̄	**31.7 A**	**28.3 B**	**23.1 C**	**16.7 D**	**15.4 D**
ss	6.2	4.8	4.9	2.6	1.4

Denemeler sonunda elde edilen vida tutma testine ait bulgular aşağıda Tablo 9'de sunulmuştur. Tablo incelendiğinde, test örneklerinin rutubet içerikleri arttığında, vida tutma kapasitesinin de azaldığı görülebilir. Genel olarak tüm gruplar arasında farklılık vardır. Ancak, yapılan Duncan testine göre, grup 4 ile grup 5 arasındaki farklılık anlamlı değildir. Rutubet içeriği ile vida tutma kapasitesi arasındaki ilişki zıt ve doğrusaldır. Masif ahşap malzeme ve ahşap esaslı kompozit malzemelerin vida tutma kapasitesi üzerine yapılan önceki çalışmalarda da benzer sonuçlar rapor edilmiştir. Vida tutma kapasitesi testi bulgularında gruplar arasında istatistiksel olarak fark olup olmadığı ANOVA testi ile araştırılmıştır. Elde edilen verilere göre; gruplar arasında istatistiksel olarak ileri düzeyde ($P<0.001$) bir farklılık olduğu tespit edilmiştir.

Tablo 9. Vida tutma testine ait veriler ve Duncan testi sonuçları (İlker, 2025)

Vida testi	Grup 1	Grup 2	Grup 3	Grup 4	Grup 5
x̄	**18.3 A**	**15.6 B**	**12.2 C**	**8.6 D**	**8.4 D**
ss	1.9	3.8	1.9	1.0	0.8

Elde edilen bulgulara göre; TKK grupları arasındaki yoğunluk farklılıklarının sonucu etkilemeyecek derece küçük olduğu tespit edilmiştir. Bu durum, yapılan çalışmada test grupları arasında, test sonucunu etkileyebilecek diğer farklılıkların olmaması bakımından önemlidir. Çünkü, masif odun ve odun esaslı kompozit malzemelerde yoğunluk, mekanik özellikler üzerinde son derece önemli bir etkiye sahiptir. Bu konuda bazı araştırmacılar tarafından yapılan çalışmalarda test örneğinin yoğunluğunun mekanik özellikler üzerine etkisi rapor edilmiştir (Kollmann ve Cote, 1968; Bozkurt ve Erdin, 1997). Bu nedenle, yapılan testler sonunda elde edilen farklılıkların yoğunluktan kaynaklanmadığını söyleyebiliriz. TKK levhaların üretilmesinde kullanılan kavak kaplamaların kusursuz, kalınlık olarak eşit, budak içermeyen ve mekanik performansı etkileyecek başkaca farklılıkların olmamasına dikkat edilmiştir. Böylece gruplar arasında homojenlik sağlanmıştır. Bu verilere göre, TKK malzemenin mekanik performansının rutubet içeriği arttıkça genel olarak azaldığını söyleyebiliriz. Ahşap esaslı kompozit malzemeler üzerine yapılan bazı önceki çalışmalarda da benzer sonuçlar elde edilmiştir. Örneğin; çam keresteden üretilen çapraz tabakalı kereste (ÇTK) test örneklerinin rutubet içeriğinin mekanik özellikler üzerine etkisi incelenmiş ve rutubetli örneklerin mekanik performansının kuru test örneklerine göre daha düşük olduğu rapor edilmiştir (Hıdır ve ark., 2024). Lee ve ark., (2001) tarafından yapılan çalışmada ise, TKK test örneklerinin rutubet içeriğindeki küçük artış ile elastikiyet modülünde azalma olduğunu bildirmişlerdir. Ladin kaplamalarından üretilen TKK levhaların eğilme özellikleri üzerine rutubet içeriğinin etkisi, Juciene ve ark., (2023) tarafından incelenmiş ve TKK panellerin eğilme dayanımı özelliklerine suyun etkisinin incelenmesi sırasında, suyun panellerin dayanımını önemli ölçüde etkilediği, kuru panelin dayanımıyla karşılaştırıldığında bir ıslatma çevriminden sonra %45'e, iki ıslatma çevriminden sonra ise neredeyse %52'ye düştüğü bulunmuştur. Bizim yaptığımız bu çalışmaya benzer bir çalışma ise Hu ve Zue (2013) tarafından yapılmış ve Kavak TKK test örneklerinin eğilme özellikleri üzerine rutubet içeriğinin etkisi araştırılmıştır. Yapılan testler sonunda, rutubet artışından TKK malzemenin eğilme direnci ve elastikiyet modülünün önemli derecede etkilendiği belirlenmiştir. Bizim yaptığımız çalışmadan elde ettiğimiz ve önceki çalışmalar sonunda elde edilen verilere göre, TKK malzemenin rutubet içeriğinin mekanik özellikler üzerine etkisi olduğu açıktır.

4 Sonuçlar ve Öneriler

Bu çalışmada; kavak ağacından elde edilen soyma kaplamalar ve FF tutkalı kullanılarak, TKK levhaları üretilmiştir. Üretilen levhalardan hazırlanan test örnekleri farklı rutubet seviyelerine şartlandırılmıştır. Toplam 5 farklı rutubet içeriğinde (%0, %10, %20, %40 ve %130) gruplar oluşturulmuştur. Bu rutubet içeriğinde iken her grup için mekanik testler uygulanmıştır. Elde edilen genel sonuçlar şu şekildedir;

- Denemeler sonunda, test örneklerinin eğilme direncinin rutubet içeriği arttıkça önemli düzeyde azaldığı belirlenmiştir. Tam kuru hale göre yaş haldeki test örneklerinin eğilme direnci %50 oranında azalmıştır.
- Test örneklerinin elastikiyet modülü değerlerinin yine önemli düzeyde azaldığı tespit edilmiştir. Tam kuru test örneklerine göre yaş haldeki test örneklerinin elastikiyet modülü değerleri %70 civarında azalmıştır.
- Eğilme testi sonunda elde edilen eğilmede deformasyon değerleri ise rutubet içeriği arttıkça artış göstermiştir. Eğilmede deformasyon değeri, tam kuru test örneklerine göre yaş test örneklerinde yaklaşık olarak 3.5 katı artış göstermiştir.
- Çekme-makaslama testi verilerinde doğrusal bir ilişki tespit edilememiştir. Bunun nedeninin bu testte etki eden faktörün sadece test örneğinin rutubet içeriği değil aynı zamanda tutkal bağında meydana gelen azalma olduğu söylenebilir.

- Statik sertlik testinde tam kuru test örneklerine göre yaş haldeki test örneklerinin sertlik değeri yaklaşık olarak %50 azalmıştır.
- Vida tutma kapasitesi testin de ise; yine rutubet içeriğinin artmasına paralel olarak direnç değerinde azalma meydana gelmiştir.

Bundan sonra yapılacak çalışmalarda, farklı ağaç türlerinden elde edilen kaplamalar ve farklı tutkal türleri kullanılarak üretilen TKK malzemenin performansı üzerine rutubetin etkisi ve ayrıca karbon elyaf veya cam elyaf ile güçlendirilmiş TKK malzemenin performansı üzerine rutubetin etkisinin araştırılması önerilir.

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Evaluation of color usage in modular children's room furniture in the last 25 years

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ABSTRACT: It is known that the use of furniture produced in a form and color suitable for the child's development provides positive contributions to the child's fine motor capacity and psychology. The main objective of this study is to analyze the transformations in children's room furniture design over the past 25 years. It was aimed to reveal the change in the use of color in modular wooden products over years. Data were obtained using literature research, examination of source data and comparative analysis methods. Following literature research and examinations, children's room furniture designs created in the early 2000s, and furniture designs created in 2025 were examined in terms of color use using the comparative analysis method. In total, furniture designs from six companies were evaluated using paired visuals targeting the same age group and functional purpose. It has been determined that more prominent colors such as were used extensively in the children's room furniture designs produced in the early 2000s, and in the following years, neutral colors and soft tones were used extensively in modular furniture designs, with a predominance of white.

Keywords: Children's room design, Modular furniture, Color use in furniture

Modüler çocuk odası mobilyalarında son 25 yıldaki renk kullanımının değerlendirilmesi

ÖZ: Çocuğun gelişimine uygun olacak biçimde ve renkte üretilen mobilyaların kullanımının çocuğun ince motor kapasitesine, bireysel gelişimine ve psikolojisine olumlu katkılar sağladığı bilinmektedir. Çalışma kapsamında çocuk odası mobilya tasarımlarında yıllar içinde gerçekleşen değişimlerin analiz edilmesi ana amaç olarak belirlenmiştir. Bununla birlikte modüler ahşap ürünlerde yıllar içinde renk kullanımında gerçekleşen değişimi ortaya koymak hedeflenmiştir. Literatür araştırmaları, kaynak verilerinin incelenmesi ve karşılaştırmalı analiz yöntemleri kullanılarak veriler elde edilmiştir. Literatür araştırması ve incelemelerin ardından, 2000'li yılların başında oluşturulmuş çocuk odası mobilya tasarımları ve çalışmanın gerçekleştirildiği 2025 yılında oluşturulan mobilya tasarımları, renk kullanımı açısından karşılaştırmalı analiz yöntemi ile incelenmiştir. Toplamda 6 farklı firmanın farklı tasarımları, aynı yaş grubuna ve aynı amaca hizmet eden ikili görseller üzerinden değerlendirilmiştir. Gerçekleştirilen karşılaştırmalar doğrultusunda 2000'li yılların başında üretilen çocuk odası mobilyası tasarımlarında daha baskın renklerin (mavi, sarı, kırmızı, yeşil, turuncu, pembe, mor, lacivert gibi) yoğun olarak kullanıldığı, sonraki yıllarda ise modüler mobilya tasarımlarında beyaz ağırlıklı olmak üzere, önceki örneklerde görülmeyen, nötr renklerin ve yumuşak tonların (bej, açık gri, vizon, açık yeşil, açık mavi, açık pembe, krem gibi) yoğun olarak kullanıldığı tespit edilmiştir.

Anahtar kelimeler: Çocuk odası tasarımı, Modüler mobilya, Mobilyada renk kullanımı.

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1 Introduction

Furniture can be defined as a universally needed product enhancing life quality by serving social, cultural, and functional human needs (Özözen, 2024). In parallel with this, furniture designs suitable for children's ergonomics are also made. Nowadays, the increase in scientific studies on child development and the more investigative attitude of parents regarding child rearing are effective in shaping the modular children's furniture sector. Previous studies on the use of color in modular children's furniture have mostly been studied with analyzes based on the current situation such as color preferences and color psychology. Uzun et al., (2017) conducted a study on the colors of youth furniture to determine what the color preferences were during the period in which the research was conducted. Zengin (2019) evaluated the design criteria in modular youth furniture and did not determine the use of color as the main issue. Jones et al., (2007), on the other hand, did not determine the color issue as the main issue while examining gender differences in modular youth and children's furniture. There is no study in the literature on the analysis of changing colors in modular children's furniture throughout the historical period.

Unlike previous studies, no analysis focusing on current preferences or trends has been conducted on this subject. Unlike previous studies, the main purpose of the study is to determine the change processes in the use of color in the production of modular children's room furniture in the last 25 years. Other purposes are to examine the effects of studies and literature research conducted in recent years on these color changes.

This study aims to examine the changes in color usage in modular children’s room furniture over the past 25 years. It also aims to identify the relationship between these changes and developments in child-centered design approaches. Additionally, it seeks to evaluate how shifting aesthetic trends have changed furniture color choices.

2 Materials and Methods

Conducting research is essential to advance scientific knowledge and ensure evidence-based understanding. Research constitutes a systematic and thorough investigation aimed at generating new knowledge and understanding of a phenomenon (Ahuja, 2001). This study was prepared considering the research concept as a basis. In this study, literature review, source analysis and comparative analysis methods were used to examine the changes in color use in children's furniture over the years. In the first stage, existing literature, academic articles, sector reports and relevant publications on color use in children's furniture design were meticulously scanned to create basic information and historical perspective on the subject.

The data obtained from the literature review were systematically analyzed with the support of reliable databases and academic archives. Both past and present sources were examined; This approach enabled comparisons of color palettes, design trends, and applications across distinct time periods in children’s furniture. The reliability of the study was ensured by comprehensive scanning of the sources.

The method used at this stage is the comparative analysis method, which was first developed by Ragin (1987) and found in the literature. Qualitative comparative analysis is a technique that allows the systematic analysis of similarities and differences between situations and cases (Ragin, 1987). The same researcher has published many articles on the subject over the years. To define the method in general;to apply qualitative comparative analysis to literature collected requires the act of reviewing each work with the goal to distinguish which causes are necessary and sufficient. This process is a systematic set of steps that should situate attributes of findings into common categories, thereby yielding a typology (Onwuegbuzie, Weinbaum, 2017). Broadly, qualitative comparative analysis is used as a theory-building approach, wherein the analyst makes connections among categories that have been identified previously, as well as to test and to develop these categories further (Miles & Weitzman, 1994).

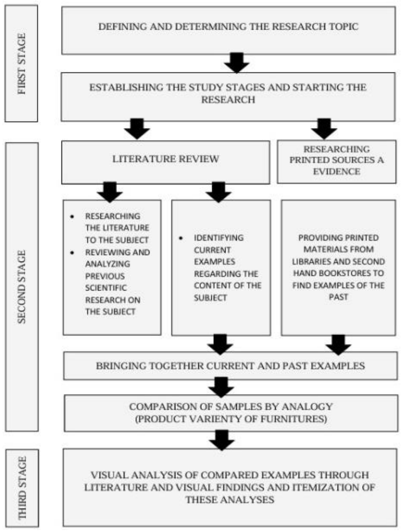

Figure 1. Methodology of the research

The findings obtained were evaluated using the comparative analysis table. With this analysis method, direct comparisons were made between the color preferences applied in the past and current applications; Color intensity, distribution and trends are clearly demonstrated (Figure 1). Thus, by systematically revealing the process of change and evolution over time, objective results have been reached regarding the development of the use of color in children's furniture. Early 2000s and current children's room furniture designs were visually compared by age group and consistent functional modules like cribs, wardrobes, beds, desks, and bookcases to ensure standardized evaluation criteria. Thus, the study systematically compared changes in the use of color in children's room furniture designs over the past 25 years were compared by obtaining more consistent results through furniture designs of the same company, appealing to the same age group and containing the same functional modules. In short, it may be possible to question the aims of the study in this direction:

- How has the use of color in modular children's bedroom furniture changed over the last 25 years?
- How do the color trends that dominated children's furniture in the early 2000s compare to 2025?
- Which trends are seen in color selection among large companies producing modular children's furniture?

2.1 Furniture and user relationship

In interior design, the most important of user requirements are physical conditions. The user's anthropometric measurements are the primary factor shaping the furniture. Then, color and material follow. Although furniture is not a vital necessity, it has always been important for humanity in the place where it is used (Boyla, 2012).

Furniture constitutes an integral part of everyday human life. When viewed in terms of adapting to daily life, it is necessary to understand the furniture in terms of the social life, technology and art environment of the region and time it belongs to (Boyla, 2012). Innovations have been seen in furniture design, especially in recent centuries. One of the main reasons for this is the development of technology. However, durability, usability and functionality have been important criteria for furniture. Meeting the needs of the user is considered to be one of the important factors.

User needs, user-centered design is not only related to the functionality of the products. The perception of any product by the user, the user's product experience and the spiritual bond he will establish with the product are also included in this (McDonagh-Philp and Lebbon, 2000). User-centered design takes into consideration important issues such as age, gender, social status, educational background, professional background and factors affecting product usage expectations and demands. What is important for some people may be unimportant for others. User-centered design includes a comprehensive research process on users' expectations, from users' interaction with the product to their views on the product's function and design (Zengin, 2019).

2.2 Stages of childhood

Like every period of life, childhood is one of the unchanging and natural parts of the life cycle (Akyüz, 2000). All individuals in childhood are protected by the United Nations Declaration of the Rights of the Child. For the purposes of this Convention, child means any human being under the age of eighteen unless the age of majority is earlier under the law applicable to the child (Unicef, 1989). The definition of childhood is based on the ‘United Nations Convention on the Rights of the Child (UNCRC)’, which defines a child as any human being under the age of 18. This framework was used to categorize the design comparisons according to developmental stages (0–6: early childhood, 7–12: middle childhood, 13–18: late childhood/adolescence) (Unicef, 1989).

In parallel with the United Nations’ demographic classification of children; target markets for modular furniture are grouped into three basic groups. These are preschool child (baby) furniture (0-6 years old), youth room (7+ years old) furniture and parent furniture. However, all this furniture can also be grouped under the title of “residential furniture” (Burdurlu et al, 2004). Children’s bedrooms require ergonomically distinct furniture, reflecting personal identity and developmental needs within individualized spatial and functional arrangements. By 16–24 months, children begin exploring surroundings via walking and climbing, requiring safe environments despite limited independent play capabilities (Campos, 2009). Between ages 3–16, children evolve from solitary play to complex socialization and autonomy, prompting significant shifts in spatial, emotional, and cognitive needs aligned with developmental and educational transitions (Campos, 2009).Since each age period has its own characteristics from birth onwards, different needs arise not only in terms of social relations and development, but also in terms of spatial structures. Regardless of these change processes, spatial designs, objects, and furniture should be suitable for childhood in total. Correct definitions and designs should be applied for these needs, which are different from those of adults.

2.3 Children's furniture

Every object or space that children come into contact with from infancy makes a significant contribution to their development. For this reason, children's furniture should be designed as specially designed objects or units that form a specific space (Salihoğlu Aydın et al., 2018). The child’s-built environment and furniture can provide children with some values such as confidence, courage, success, belonging, freedom, usage or alternative thinking. Together with these values, the child can discover himself and form his personality and identity. For example, the use of color in the space sharpens the child's gender preferences, ergonomic sizing gives the child a sense of freedom, and play spaces based on adventure and creativity and containing rich stimuli allow children to discover their potential and boundaries and define themselves (Salihoğlu Aydın et al., 2018). The domestic studies on the color design of children’s furniture indicate that the color of children’s furniture usually tends to be lively and light warm colors (Lin & Yuriiovych, 2024). Having soft tones of furniture in the spaces used by children increases their focus and creativity. For this reason, the use of soft tones contributes positively to the development of children (Iliev, 2021).

There are many product groups that children can use at home, outdoors or in educational institutions. Modular children's furniture used in residences is the most basic product of children's furniture requirements. Due to the diversification of these products and the variability of forms, it can meet the growth needs of children for sustainable use.In particular, modular design production as a systematic design method can shorten the product design cycle, thus reaching more users.However, when examining the existing modular children's furniture in the market, it was found that most of the products are only functional and ignore the emotional needs of users such as intelligence and interest satisfaction during interaction with the products. For this reason, conducting research in the field of modular children's furniture will benefit children's development. This can also be considered as a social and community contribution. Conducting research and studies on the design of modular children's furniture can also further improve product satisfaction. Apart from this, it can also offer a new and effective discovery for modular children's furniture design (Ye at al., 2021). Children’s room furniture must anthropometrically support physical development, autonomy, and safe spatial interaction during early childhood’s formative home experiences. Children’s rooms should include accessible, modular, and mobile storage units and essential furniture to support autonomy, self-care, and developmental needs during early childhood’s dynamic growth period (Demirarslan, 2019).

2.4 Modular children's room furniture in the last 25 years

Comparative visuals were created to reveal the changes in color usage in children's room furniture designs in the last 25 years. Since the design approaches of the companies may differ from each other, the visuals used in the comparison were selected from the children's room designs created by the same company in different years. Although the requirement to have served in the modular children's furniture sector for at least 25 years reduced the number of samples examined due to the comparison made on the same company, the limitations of the study were not changed in order to obtain reliable data. The comparison was made on a total of 20 children's room designs from 6 different companies. The children's room designs offered for sale by the companies since the early 2000s were compared with the designs currently sold by the same companies in 2025.

While determining the companies that will form the sample within the scope of the study, two main criteria were taken into consideration. It was taken into consideration that the companies were large-scale companies operating in more than one country and that they had been producing in the same field and with the same product groups since the beginning of the 2000s in order to be able to make comparisons between furniture designs. In addition, in order to be able to make comparisons through visuals, it was another important factor that was effective in determining the samples that the documents of the furniture designs of the companies were accessible in the early 2000s.In this comparison, the company names were kept confidential and the companies were expressed by coding them with letters. In the images, those marked with the letter a show the designs between the years 2000-2010, and those marked with the letter b show the product designs of the year 2025.

Figure 2. Examples of color usage in the baby room set of company A (a:Tasarım Publisher; b: URL 1, 2025)

Baby room furniture also includes parental use, especially since the child does not have the opportunity to use it in early infancy. In the modular children's furniture example shown in Figure 2, it is seen that the company produces the furniture with functionally the same parts, but there is a radical change in the use of color .

Figure 3. Examples of color usage in the children's room set of company A (a: Tasarım Publisher; b: URL 2, 2025)

In children's room furniture, it is not ergonomically possible to use the furniture used for the baby in later years. In this direction, different modules are produced for the 6+ age group in the modular furniture production. For example, the protected small bed is replaced by a single bed in the production for this age group (Figure 3). Bunk bed children's room designs, which are frequently used in children's rooms for use by more than one child, increase space usage performance (Figure 4).

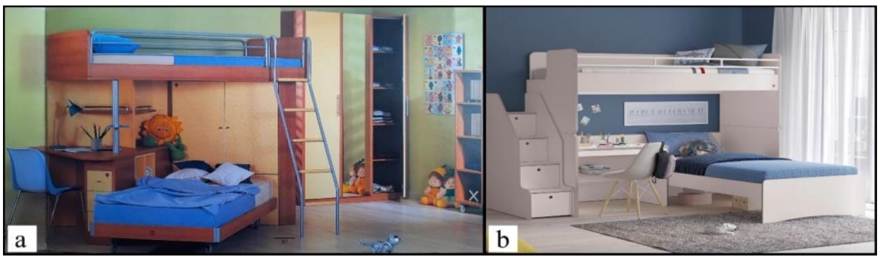

Figure 4. Color usage examples of bunk bed children's room set of company A (a: Tasarım Publisher; b: URL 3, 2025)

Figure 5. Examples of color usage in the children's room set of company A (a: Tasarım Publisher; b: URL 4, 2025)

Examples of side-protected beds or corners with soft, circular forms are mostly produced for early childhood periods (Figure 5).

Figure 6. Color usage examples of bunk bed children's room set of company A (a: Tasarım Publisher; b: URL 5, 2025)

These models, which increase space utilization, can also be produced in stacked models and with narrow stairs (Figure 6).

Figure 7. Examples of color usage in the children's room set of company A (a: Tasarım Publisher; b: URL 6, 2025)

There are no examples of the use of red, which is a very active color, in recent years. However, the use of this active color is seen in the 2000s. In modular furniture, this type of color use is seen in most of the examples where it is determined that it remains fixed with elements such as covers or headboards and is not used on the body (Figure 7).

As previously stated in the literature research, early children's need for their own indoor space is a necessity for creativity and expression. Although there are great changes in the colors of the furniture, the modular production of low bunk beds (high beds) for early childhood did not show significant differences in terms of functionality (Figure 8).

Figure 8. Color usage examples for the high bed children's room set of company A (a: Tasarım Publisher; b: URL 7, 2025)

Figure 9. Examples of color usage in the children's room set of company A (a: Great Ideas for Kids Rooms, Parragon Publishing; b: URL 8, 2025)

While modular youth rooms with the same functions and parts were produced with a clearly sexist approach in the early 2000s, today's examples do not have any sexist colors or models (Figure 9).

Figure 10. Examples of color usage in the baby room set of company B (a: Tasarım Publisher; b: URL 9, 2025)

Crowning protected beds with a mosquito net in baby room furniture is one of the few design elements that does not change (Figure 10).

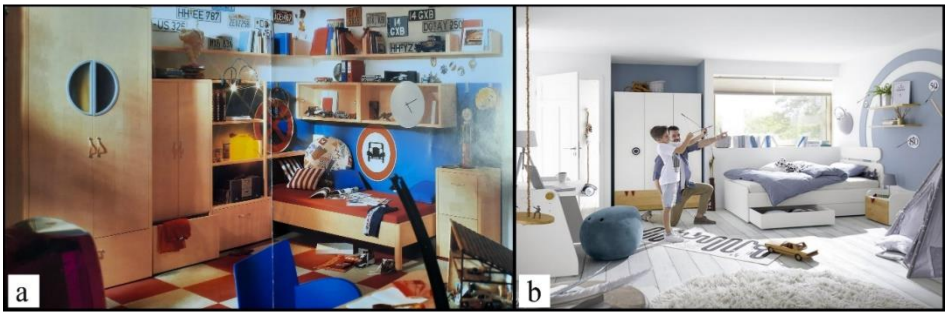

Figure 11. Examples of color usage in the children's room set of company B (a: Tasarım Publisher; b: URL 10, 2025)

Although the use of white color was almost never seen in the 2000s, the most dominant color in recent years is white in many examples (Figure 11).

Figure 12. Examples of color usage in the children's room set of company B (a: Tasarım Publisher; b: URL 11, 2025)

The striking colour use of late childhood furniture in the 2000s has given way to simplicity in today's furniture, as in other examples. It is seen that this situation is not limited to furniture, and even the colours used in wall paints are preferred in more neutral and pastel tones today (Figure 12).

Figure 13. Examples of color usage in the children's room set of company C (a: Tasarım Publisher; b: URL 12, 2025)

Movable modules and intricate design examples can be encountered in children's room furniture designed in the 2000s. In contrast, in furniture created today, simplicity is preferred in terms of functionality as well as in the use of color (Figure 13).

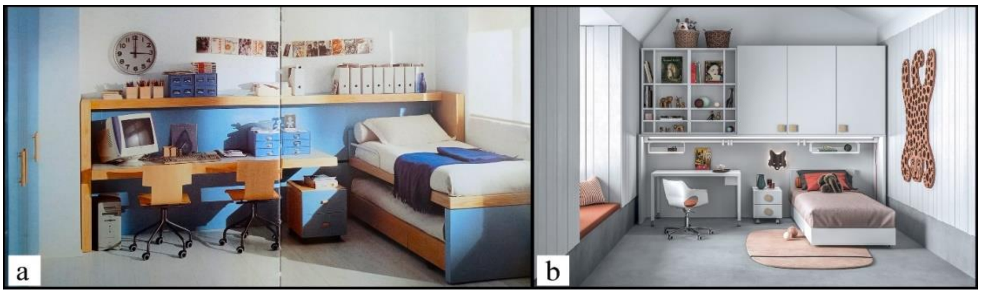

Figure 14. Examples of color usage in the children's room set of company C (a: Tasarım Publisher; b: URL 13, 2025)

Design examples where the headboard is evaluated as a whole with units serving different purposes such as tables, cabinets and shelves can be seen today, as they were in the 2000s. However, despite the design similarities, there has been a major change in the use of color (Figure 14).

Figure 15. Examples of color usage in the children's room set of company D (a: Tasarım Publisher; b: URL 14, 2025)

Examples of children's room furniture designs, where the room interior is used more systematically and define more private space for children, can be seen today, as they were in the 2000s. However, in terms of color usage, it is seen that simpler colors such as white, beige, and cream are preferred instead of vibrant primary colors (Figure 15).

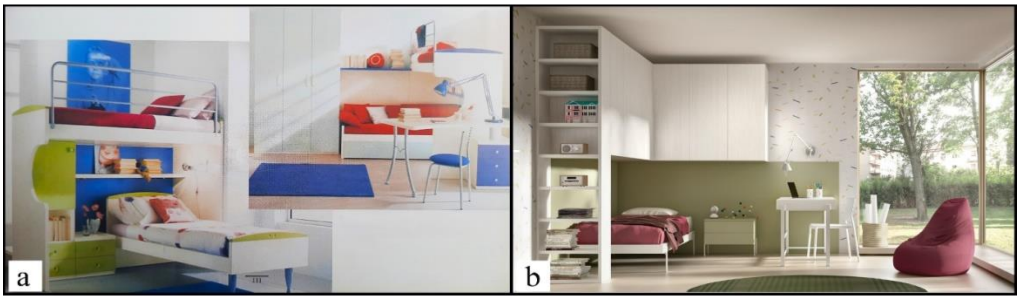

Figure 16. Examples of color usage in the children's room set of company D (a: Tasarım Publisher; b: URL 15, 2025)

In children's room furniture designed in the 2000s, examples of more than one primary color being used together in the same module can be seen. In today's designs, it is seen that pastel tones of colors are preferred even if a second color is used next to a neutral color (Figure 16).

Figure 17. Examples of color usage in the children's room set of company D (a: Tasarım Publisher; b: URL 16, 2025)

In our children's room furniture designs, examples are seen where wood texture is included in the design as well as neutral and pastel tones. However, it is seen that the wood colors used here are preferred in light soft tones rather than dark tones (Figure 17). Today, Montessori beds, which are produced as an alternative to cribs, are widely used in baby room furniture designs. These beds also allow children to use their beds on their own in later years. The simplification in colors is striking (Figure 18).

Figure 18. Examples of color usage in the baby room set of company E (a: Tasarım Publisher; b: URL 17, 2025)

Figure 19. Examples of color usage in the children's room set of company E (a: Tasarım Publisher; b: URL 18, 2025)

While primary colors were used extensively in late childhood children's room furniture designs in the 2000s, neutral colors are preferred in today's designs in order to appeal to more general taste criteria (Figure 19).

Figure 20. Examples of color usage in the children's room set of company F (a: Tasarım Publisher; b: URL 19, 2025)

In the designs created in the late childhood children's room furniture in the 2000s, it is seen that wood texture with dominant tones was used as well as vibrant tones. In today's furniture designs, it is seen that completely plain neutral colors are preferred (Figure 20).

Figure 21. Examples of color usage in the children's room set of company F (a: Tasarım Publisher; b: URL 20, 2025)

Although the desks and bookcases, which are the working units in children's room furniture, have not changed in terms of functionality, there are differences between the designs of the 2000s and today in terms of the use of color. Today, the preferred colors as alternatives to white are beige, cream, light gray (Figure 21).

3 Findings and Discussion

Within the scope of the research, modular children's room furniture produced in the early 2000s and modular children's room furniture currently in production in 2025, when the study was conducted, were compared based on user-oriented models, primarily in terms of color use. The companies included in the research were selected from companies operating in Turkey and different countries of the world. In order to obtain reliable data as a result of the comparison, the visual of the children's room set offered for sale by the same company since the early 2000s and the visual of the children's room set on sale in 2025 were used. No comparisons were made between different companies. In the study where a total of 6 companies' children's room furniture designs were evaluated within themselves, 8 designs belonging to company A, 3 designs belonging to company B, 2 designs belonging to company C, 3 designs belonging to company D, 2 designs belonging to company E and 2 designs belonging to company F were compared. The children's room designs of the companies between 2000-2010 and the children's room designs in 2025 were compared in the form of binary images by obtaining 20 shapes from a total of 40 images.

When the children's room furniture designs were examined in terms of color use in the 20 comparisons made on the companies, it was seen that the companies used colors such as red, blue, yellow, pink, orange, green, purple, and navy blue intensively in their designs in the early 2000s. It is also striking that the colors were used not with their subtones but with their main tones (Figure 22). In contrast, it is seen that colors were used quite a lot, not as eye-catching design elements in small sections of the furniture, but rather in a way that covered the vast majority of the furniture surfaces. In fact, this multi-colorfulness is not limited to furniture alone, but also appears on the walls of the rooms, auxiliary elements, and accessories.

Another striking issue in the comparison is that colors were used with a sexist approach in some of the children's room furniture designs made in the early 2000s. While blue and yellow colors are predominantly used in furniture designed for boys, pink, purple, and red colors are predominantly used in furniture produced for girls.

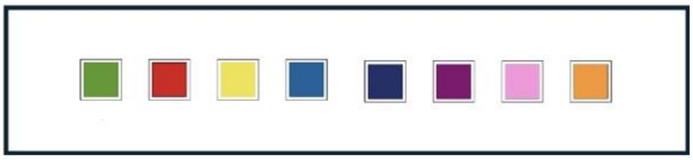

Figure 22. Colors used in children's room furniture in the early 2000s, obtained from company catalog images

When the use of colors in children's room furniture designs that companies will continue to produce and sell in 2025 is examined, it is seen that the use of colors such as red, blue, yellow, pink, orange, green, and purple in main tones has decreased to almost zero. It is striking that the vast majority of furniture is designed in more neutral colors such as white, cream, beige, light gray, and mink. When we look at the colors used in some designs, it is seen that softer pastel tones are preferred, and the dominance of colors and the intensity of use are reduced (Figure 23).

Figure 23. Colors used in children's room furniture in 2025, obtained from company catalog images

It is seen that dominant colors are used as design elements in small sections of furniture, in auxiliary elements and accessories, and thus a visual balance is achieved. It is also noteworthy that the gendered approach to color usage in today's children's room designs has decreased and colors are not separated according to girls and boys.

In order to examine the colors, sample sets were selected from similar products and designs. Although this selection created a very limited area of examination, a study was conducted in which the color, not the form, was examined. Within the similarities in the design form, the transformation in the context of color and aesthetics was interpreted together with the functional continuity of modular children's furniture.

• It was determined that the colors used in furniture produced in the early 2000s and the colors used in furniture produced in 2025 differed significantly. The factors affecting this difference are periodic changes in design approaches, technological changes based on production, and pedagogical approaches carried out on children. Approaches in the literature have also differed in the last 25 years regarding the psychological effects of colors on children.

• When the findings obtained as a result of the study were examined, it was seen that in the children's room furniture designs produced in the early 2000s, colors such as blue, red, yellow, green, orange, pink, purple, and navy blue were used intensively in their main tones.

• When the children's room furniture designs produced in 2025 were examined, it was seen that colors such as white, cream, beige, light gray, and mink were used intensively in the furniture. It is noteworthy that in furniture where colors are used, colors are used in softer tones rather than dominant tones.

• In the early 2000s, examples of modular children's furniture that were clearly separated as girls and boys not only in terms of color but also in terms of form with a gendered approach have completely disappeared. Instead, in today's examples, examples that do not contain any gender expression are used in both color and form. In addition, this also facilitates streamlined production processes for manufacturers.

• Transition from Aesthetics to Function: It has been determined that the use of color is no longer just an aesthetic element, but has become a functional component that supports child development.

• Continuity of the Modular Structure: Despite the change in colors, it has been observed that the formal differences in modular furniture forms (bunk beds, high beds, etc.) are limited and the functional structure is preserved.

• Evolution of User Preferences: The findings show that users (especially parents) care more about criteria such as aesthetic simplicity, timelessness and genderlessness.

• Consistency with Literature: The findings are directly related to the increasing research focused on pedagogical design, attention management and child psychology in recent years.

• Commercial Compliance and Mass Production: Increasing color standardization reduces production costs for manufacturers and can make it easier for products to appeal to a wide range of users.

• Potential for Interdisciplinary Contributions: This research points out that in the design of children's room furniture, collaboration should be made not only with architecture and design but also with fields such as child development, psychology and educational sciences.

• Compliance with Pedagogical Data: This transformation in color choices coincides with current scientific research that supports children's attention, emotion and behavioral development.

4 Conclusion

- In 25 years, children’s furniture colors shifted from vibrant primaries to neutral tones, reflecting evolving aesthetic, scientific, and pedagogical perspectives on child development.
- One of the important changes, the use of color, was tried to be determined by keeping other factors constant in the modular children's furniture that constitutes the subject of the study. The following results were obtained in this study conducted on the use of colors in children's room furniture designs in the last 25 years.
- Another factor affecting this preference is the flexible space concept that can be updated over time. Since children change rapidly in a short time, their needs and taste criteria change over time. It is easier to add new modules to a children's room furniture created in colors such as white, cream, beige, gray in line with the needs over time, without disrupting the aesthetics. In addition, a children's room where these colors are preferred ensures that the products can be used for many more years in terms of still being able to respond to the changing taste criteria of the child over time. It can be stated that this color approach that supports sustainability has shown positive changes in modular children's furniture in recent years with scientific research and user preferences. However, when looked at as a whole, the research concluded that, due to all the reasons mentioned, children's room furniture designs using neutral colors are produced more and preferred by users more today.
- In conclusion, the change in color usage observed in modular children's furniture is not only an aesthetic transformation; it is also a holistic reflection of pedagogical, cultural and functional factors. These findings point to the importance of prioritizing child development-centered, sensory-balanced and sustainable approaches in future furniture designs.

Authors’ Contribution

Gizem Özer Baş: Conceptualization (development of research idea and aims), conducting research, resources, drafting an article, writing an article, reviewing and editing. **Eymen Tatlıhayat:** Conducting research, conducting analyses, data curation, visualization, writing article.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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Mobilya ve Ahşap Malzeme Araştırmaları Dergisi

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Mobilya tasarımında "esinlenme"- "tarihsel aktarım"- "yenilik" ilişkisinin retrospektif-prospektif bir çalışma üzerinden değerlendirilmesi

İsmail Bezci[1]*, Vildan Dündar Türkkan[2], Gülçin Cankız Elibol[1]

ÖZ: Çalışma, mobilya tasarımında tarihsel süreç verilerinin, esinlenme aşamasında ne şekilde kullanılabileceğine yönelik bazı öneriler sunmayı amaçlamaktadır. Bu amaçla, öncelikle esinlenme konusu genel olarak ele alınmış; yenilik ile olan ilişkisi temel çerçevede tartışılmıştır. Mobilya özelinde, geçmiş verilerinin, dönemler boyu çeşitli şekillerde mevcut dönemlere aktarıldığı görülmektedir. Bu aktarımın gerek biçimsel gerekse anlamsal olabildiği söylenebilecektir. Bu makale, söz konusu tarihsel unsurların, birer esinlenme nesnesi olarak alındığı ve benzer genetik kodları içeren "yeni" tasarımların ortaya konduğu bir çalışmanın analizini sunmaktadır. Bu kapsamda yapılan analizde, tarihsel süreç verilerinin, mobilya tasarımları üzerinden ne şekilde okunduğu; tanımlama sıfatlarının ne şekilde belirlendiği; bu mobilyaların birer esin kaynağı olarak oynadıkları roller; tanımlama sıfatlarının ortaya konacak yeni mobilyalarda ne şekilde yer aldığı ve sonuç ürünlerin biçimsel ve anlamsal verileri değerlendirilmiştir. Retrospektif verilere dayalı prospektif bir yaklaşım sunan bu analizin, mobilya tasarımında, özü anlama ve yorumlama konusunda yeni bir bakış açısı sağlaması beklenmektedir.

Anahtar kelimeler: Mobilya, Tasarım, Mobilya tarihi, Esinlenme, Yenilik

Evaluation of the relationship between "inspiration"-"historical transfer"- "novelty" in furniture design through a retrospective-prospective study

ABSTRACT: The study aims to provide some suggestions on how the historical data may be used in the inspiration phase of furniture design. For this purpose, firstly, inspiration, as an aspect, is discussed in general and its relationship with novelty is discussed basically. In furniture field, it is seen that past data are transferred to the current periods in various ways throughout the periods. It can be said that this transfer can be either formal or semantic. This article presents the analysis of a study in which these historical elements are taken as objects of inspiration and 'new' designs containing similar genetic codes are put forward. In this context, the analyses evaluate how those historical data are read through furniture designs; how the defining adjectives are determined; the roles played by this furniture as sources of inspiration; how the defining adjectives are included in the newly designed furniture and the formal and semantic data of the final products. This analysis, which presents a prospective approach based on retrospective data, is expected to provide a new perspective on understanding and interpreting the essence of a design.

Keywords: Furniture, Design, Furniture history, Inspiration, Novelty

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1 Giriş

Kalfaoğlu Hatipoğlu ve Koç Aytekin (2020)'e göre, sürdürülmek istenen özü, zamana ait üslubu ve tasarım kararlarını anlamak ve anlamlandırmak için kodların analiz edilmesi gerekmektedir. Tasarımda özün sürdürülebilmesi için bu kodların doğru şekilde anlaşılması ve uygulanması önem arz etmektedir. Doğrudan ve dolaylı olmak üzere iki tipi olan bu sistemde, dolaylı anlatım, soyut anlatı içeren kodları, yani öz ve anlama ilişkin değerleri; doğrudan anlatım ise biçimsel olguları ifade etmektedir (Kalfaoğlu Hatipoğlu ve Koç Aytekin, 2020: 1679-1683).

Dış ortamdan alınan görsel ve kavramsal verilerin tümü tasarımcının esin kaynakları olarak tanımlanabilecektir. Bu veriler, tasarımcının kişisel özellikleri ve deneyimleri doğrultusunda zihinde işlenerek yaratıcı fikirlere dönüşebilecektir (Gürcüm ve Kartal, 2021: 546). Bu da esinlenmenin tasarlama sürecinin başlangıç noktası olarak çok önemli bir yere sahip olduğunu göstermektedir. Tasarımcı, esinlendiği kavramdan, olgudan, hikâyeden yola çıkarak özgün, kendisini anlatan ve katma değeri olan eser, ürün veya koleksiyon ortaya koymak için esin kaynağının ya da örnek olayın bağlamını, kavramsal çerçevesini ve içeriğini araştırmak ve tasarıma ulaşmak durumundadır (Gürcüm ve Çiftçi, 2017: 2).

Esinlenme, tasarımda yer alan fikir kaynaklarının spesifik kullanımları için belirli terimler sunmaktadır. Bunlar, başlangıç tasarım (yeni bir tasarım oluşturmak üzere geliştirilen bir tasarım); örnek (yeni tasarımlara ilham veren mevcut yapılar vb); yeniden kullanım (mevcut bir bileşenin yeni bir içerikte kullanılması); model (bir çözüm ilkesi sunulması) ve birincil üretici (tasarımı şekillendiren problemin açık ve net bir özelliği) olarak belirtilebilir (Eckert ve Stacey, 2000: 524).

"Tasarım kavramı esas olarak son ürünün görselliğini oluşturmada etkinken, esin kaynağı tasarımın başlangıç noktasında ve tasarımın bilişsel pek çok anında önemli algısal ve kavramsal bilgiler ortaya koyan bir kaynak olarak görev yapmaktadır. Esin kaynağından transfer edilen tasarım verisi yaratıcılığın da etkisiyle tasarımcıyı sınırsız yaratımlara taşırken, tasarım konsepti tasarımcının çizilen çerçeveden uzaklaşmaması için adeta bir uyarıcı görevi görmektedir." (Gürcüm ve Kartal, 2021: 550).

Esin kaynağı, tarihsel süreçten herhangi bir oluşum, bir sanat eseri, bir kavram veyahut tasarım eylemini tetikleyecek herhangi bir unsur olabilecektir. Buradaki en önemli ayrım, esinlenmenin kesinlikle bir kopyalama, bir taklit aracı olmadığının; yeni tasarımlara yön verebilecek bir çıkış noktası olabileceğinin algılanmasıdır. Bu süreçte, birçok farklı sanat dalı arasında neredeyse tüm dönemlerde etkilenmelerin ve esinlenmelerin olduğu gözlenmektedir. Bu etkilenme kimi zaman tek yönlü, kimi zaman ise karşılıklı bir etkileşim şeklinde olabilmektedir (Elibol ve ark., 2019: 154).

Örneğin; Gürcüm ve Çiftçi (2017)'ye ait bir çalışmada, Barok üslubu, tekstil tasarımında esin kaynağı olarak belirlenmiş; ortaya konan sonuç tasarımlarda bu üsluba ait gerek soyut gerekse somut niteliklerin yansıtılması gerektiği, söz konusu niteliklerin tanımlanmasıyla birlikte vurgulanmıştır. Bir başka çalışmada (Özkan ve Öztürk, 2023), ikonik mobilya tasarımları tarihsel analiz, tasarım yönünden analiz ve etki analizlerine konu edilmiş; modernizmin bir akım olarak mobilya tasarımları üzerindeki etkileri incelenmiştir. Mobilya tasarımında geçmişe duyulan ilgi ise bir başka çalışmada (Yararel Doğan ve ark., 2022) ele alınmış; bulgular genel olarak değerlendirildiğinde, cinsiyet ve yaş değişkeninden bağımsız olarak, bireylerin geçmişe özlem duyduğu yorumuna varılmıştır. Elde edilen bulguların, retro mobilya üretimi yapan markalar tarafından dikkat çekici bir pazarlama unsuru olarak kullanabileceği de belirtilmiştir (Yararel Doğan ve ark., 2022: 591).

Çorbacıoğlu (2022)'na göre ürünler, mesaj ve anlam taşıyıcı olma özellikleri aracılığıyla, birer iletişim aracı olarak görülmektedir. Ürün kendi ekosistemi içinde anlam üretmektedir. Tasarımcılar, kullanıcılar, kültür, çevre, görsel ögeler, malzemeler, renk gibi girdiler de anlam oluşum sürecine etki etmektedir ve her ürün bir anlam taşıyıcıdır. Ürünler insanlarla, kültürlerle farklı anlamlar kazanmakta, değişmekte ve geliştirilmektedir (Çorbacıoğlu, 2022: 752, 758). Can ve Gürpınar (2021)'e göre, bu bağlamdaki kilometre taşları, yalnızca belirli bir dönemi tanımlamakla kalmaz, aynı zamanda birçok katmanlaşmış bağlamda mobilya tasarımı alanındaki operasyonel, ideolojik, teknolojik, morfolojik değişiklikleri de temsil eder.

Ultav ve ark., (2021)'na göre; bir ürünün materyalliği konusunda inceleme yapmak, tasarım tarihinin, ekonomik, kültürel ve toplumsal gelişmelerle bağlantılı olarak okunmasına izin vermektedir. Bu bağlamda, Ultav ve ark., (2021), bir mobilya parçasının malzeme niteliklerini anlamanın, sadece formlara veya stillere değil, aynı zamanda kültürel üretimlere de dayalı sonuçları ortaya koyduğunu belirtmektedir.

Bu noktada gerek işlevsel, gerek kültürel, gerekse biçimsel yön barındıran bir ürün olan mobilya, temel işlevlerinin yanında, "anlam" taşıma konusunda da neredeyse tüm dönemlerde önemli görevler üstlenmiş bir ürün olarak karşımıza çıkmaktadır.

Günümüzde ise rekabet artışıyla birlikte, işletmelerin varlıklarını sürdürebilmeleri için sürekli olarak yeni ve çekici ürünler tasarlamaları ve geliştirmeleri ihtiyacı doğmuştur. Dolayısıyla, görsel olarak daha fazla ilgi çeken ve tüketicilerin talep edebileceği mobilyaların tasarlanması, tasarımcılar ve üreticiler için önemli bir gündem konusu durumundadır (Göktaş ve ark., 2024: 205). Zira yenidünya düzeni ve tüketim anlayışı, üreticiyi buna zorlayabilmektedir. Ancak tasarımda, ilgi çekmenin ötesinde kaygılar da barınmaktadır. Yeni bir tasarım ortaya konurken gözetilen tutarlılık ve kuvvetli kavramsal alt yapı gibi etkenler, ortaya konan ürünün salt satış değil, bir kültür nesnesi olarak da nitelendirilebilmesini sağlayabilecektir.

Mobilya, tasarım özelinde ele alındığında, tasarım girdilerinin, işlevsel, biçimsel ve anlamsal yönde olabildiği görülmektedir. Bu girdilerin her biri bir diğerini de etkileyebilecek nitelikte ve önemdedir. Ancak her tasarımda, bu girdilerin, öğelere eşit ağırlıkta ve etkide yansıması söz konusu olmamaktadır. Kimi tasarımlarda işlevsel yön ön planda tutulurken; kimi tasarımların içermesi öngörülen ve aktarması beklenen anlam, bir manifesto niteliğinde dışa yansıyabilmektedir. Tarihsel süreç, bu üç unsurun dinamik dengesini; hatta kimi zaman tek yöne kayan baskınlığını yansıtan birçok örneğe sahiptir. Her biri ayrı değerde olan bu tasarımlardan bazıları ise bu çalışmada ele alınan uygulamanın çıkış noktası, esin kaynağı konumundadır.

Çalışma bu yönüyle retrospektif bir yol izlemektedir; bir başka anlatımla tarihsel süreç içerisinde geriye dönük bir bakış sunmaktadır. Tasarım literatüründe bu yönde kimi çalışmaların (Doğan, 2015) bulunduğu görülmektedir. Retrospektif çalışmalar betimleyici veya analitik olabilmektedir (Talari ve Goyal, 2020: 398). Çalışma, bu bağlamda, betimleyici retrospektif bir araştırma niteliğindedir. Özhan Çaparlar ve Dönmez (2016)'e göre, bilimsel araştırmalar, veri toplama tekniklerine göre, nedensellik ilişkilerine göre, zamanla ilişkisine göre ve uygulandığı ortama göre sınıflandırılabilmektedir. Zamanla ilişkisine göre yapılması öngörülen sınıflandırma ise retrospektif, prospektif ve kesitsel olmak üzere üç kategoride yer almaktadır. Bu çalışmaya bu bağlamda bakıldığında ise çalışmanın, gerek geçmişe yönelik analizler ve betimlemeler içermesi, gerekse geleceğe yönelik sentezler sunması bakımından her iki unsuru da barındırdığı görülmektedir.

Çalışmanın amacı, esinlenme, analiz -ve bu yolla tarihsel aktarım- ve belirlenen kodları taşıyan yeni tasarımların ortaya konması ile mobilya tasarımı konusuna yeni bir bakış açısı sunmak ve bir metot önerisinde bulunmaktır. Gerçekleştirilen analiz kısmı, çalışmanın araştırma ve değerlendirme kısmını; belirlenen kodların taşınması ve içinde bulunulan zamanın ve koşulların etkisiyle yeni tasarımların ortaya konması ise çalışmanın özgün bulgu kısmını oluşturmuştur.

2 Metot

Çalışma, Hacettepe Üniversitesi, Güzel Sanatlar Fakültesi, İç Mimarlık ve Çevre Tasarımı Bölümü'nde verilmekte olan İÇT436 Mobilya Tasarımı dersinde, yazarlar tarafından yürütülmüş olan bir çalışmada elde edilen verilerden bir seçkiyi içermektedir. Çalışma, nitel bir araştırmadır. Veri toplama söz konusu olmamıştır. Araştırma yöntemi, doküman taraması ve doküman analizine dayanmaktadır. Bu sebeple Etik Kurul onayı gerekmemiştir.

Çalışmada, öğrencilerden öncelikle mobilya tarihi alanında geniş bir literatür ve görsel taraması yapmaları ve eş zamanlı olarak kendilerini yansıtan 5 adet sıfat bulmaları istenmiştir. Burada hedef, çıkış noktası olarak kabul edilebilecek bazı kavramların, temaların belirlenebilmesidir. Bu noktada yola çıkılacak kavramlar, sıfatlar, tasarımcının kendisi olmak durumunda değildir; bir tasarım özeti veya temel hedefler üzerinden de gidilebilecektir. Bu çalışmanın söz konusu aşamasında öznel bir yol izlenmiş ve sanatsal bağlamda kalınarak yukarıda belirtildiği şekilde sıfatlar belirlenmiştir.

Bir sonraki aşamada, bu sıfatlar ile gerek biçimsel gerekse anlamsal yönden bağdaşabilecek mobilyalar seçilmiştir. Dönem ve stil konusunda herhangi bir kısıtlamaya gidilmemiştir. Burada, esneklik sağlanabilmesi bakımından önce birkaç adet mobilya seçilmiş; daha sonra tek mobilya üzerinden analizlere başlanmıştır. Bu aşama, çalışmanın öznel yönünü oluşturmaktadır. Burada amaç, herhangi bir çıkış noktası, bir esin kaynağı benimsenmesidir. Dolayısıyla, seçilmesi öngörülen kaynak mobilyalara yalnızca bu açıdan bakılmış; bu seçimin nesnel bir temele dayandırılması beklenmemiştir.

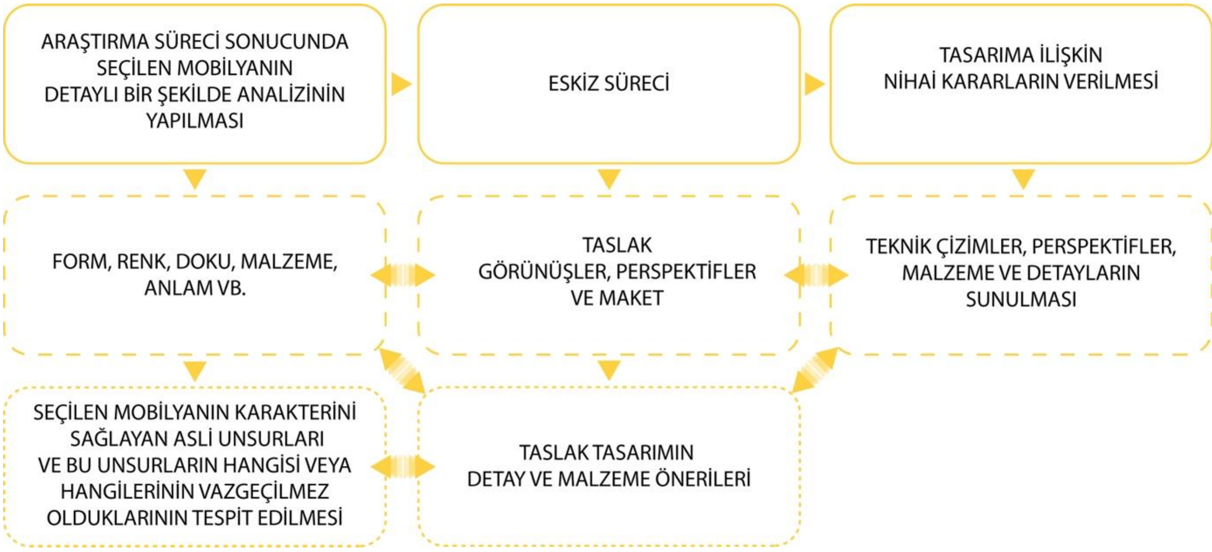
Öncelikle, belirlenen sıfatların, seçilen mobilyalar ile ne yönde bağdaştıkları tartışılmıştır. Bu aşamada, gerek biçimsel, gerek işlevsel, gerekse anlamsal yönlerden incelemeler ve analizler yapılmıştır. Biçimsel yönden veri sunan yapısal özellikler, yani geometrik yapı da dahil olmak üzere tüm formel özellikler, kullanılan renkler, malzemeler, dokular analiz edilmiştir. Bu özelliklerin bir kısmının, anlamsal işaretler de verebileceklerinden, mobilyalar, bu unsurlara dayanılarak anlamsal yönden de analiz edilmiştir. İşlevine işaret eden unsurlar da değerlendirmede dikkate alınmıştır.

Bu analizi takiben, tespit edilen noktaların hangilerinin, mobilyanın karakteri anlamında vazgeçilmez olduğunun değerlendirilmesi aşamasına geçilmiştir. Kimi unsurlar karaktere yön veren asli unsurlar olarak saptanmış ve muhafaza edilmek üzere tasarım sürecine kaydedilmiş; kimi unsurlar ise tali unsurlar olarak belirlenmiş ve elenebilir nitelikte olmak üzere not edilmiştir. Eş zamanlı olarak eskiz süreçleri başlatılmıştır. Bu aşamada manuel yollar öncelikle tercih edilmiştir.

Eskizler, analizler sonucunda belirlenen öğeler ışığında taslak tasarımlara ve taslak maketlere dönüşmüştür. Bu aşamada, devreye, detay ve malzeme önerileri de girmeye başlamıştır (Şekil 1).

Çok girdili bir süreci içeren bu analizlerde, yeni tasarıma ilişkin nihai kararlar verilirken, kaynak mobilyanın özünden kopmamaya dikkat edilmiş; ancak onun kopyası veya taklidi olmayan, onun yalnızca tasarım kodlarını, bir nevi genetik kodlarını içeren bir "sonraki neslinin", bir başka anlatımla "torununun" ortaya konması hedeflenmiştir. Retrospektif bir yaklaşımla gerçekleştirilen analiz aşaması, prospektif bir sentezle nihayetlendirilmiştir.

Bu analiz ve sentez esnasında "esinlenme" ve "tarihsel aktarım" kavramları arasındaki denge, "yenilik" yönünde korunmaya çalışılmış; ortaya konan her tasarımın, rafine tarihsel referanslar içeren, bu yolla geçmişe saygısını ileten, "yeni" tasarımlar olmalarına azami özen gösterilmiştir. Tasarımlar, yazarların yönlendiriciliğinde, öğrenciler tarafından gerçekleştirilmiştir.



Şekil 1. Analiz ve sentez süreçleri (Yazar tarafından hazırlanmıştır).

3 Bulgular ve Tartışma

Bu çalışmada, metot başlığı altında açıklanan analiz ve sentez süreçleri sonucunda elde edilen tüm tasarımlara yer verilmesi, sayının yüksekliği itibariyle mümkün olmadığından, süreci ve metodu tüm girdileriyle yansıtan birkaç örneğin sunulması yoluna gidilmiştir. Temel bulgu niteliğindeki bu örnekler aşağıda sunulmuştur. Örneklerin sunulması esnasında, 5846 sayılı Fikir ve Sanat Eserleri Kanunu kapsamında, eser sahibinin haklarının gözetilmesi bakımından, uygulama esnasında yeni tasarımı geliştiren tasarımcının adının açık olarak belirtilmesi yoluna gidilmiştir.

3.1 Tasarım 1 – dikiş masası – hazneli masa

Tasarım 1, Şekil 2'de sunulmuştur. Analiz aşamasından önce tasarımcı tarafından ortaya konan sıfatlar, Belirgin, Tedirgin, Kararsız, Enerjik ve Hayalperest olarak belirlenmiştir. Bu sıfatları çağrıştıran mobilyanın belirlenmesinden sonra, belirlenen mobilyanın yapısal yani biçimsel, işlevsel ve anlamsal analizleri yapılmıştır.

Esin kaynağı mobilya, 19. Yüzyıla özgü bir dikiş masasıdır. Masif ahşap, ince, zemine doğru incelerek inen, uzun ayaklara sahip; eliptik, açılabilir üst tablalı ve alt kısmında kumaş haznesi olan bir mobilyadır. Barok (Louis XIV) ve Rokoko (Louis XV) arasındaki döneme adını veren Regénce dönemine ait bir mobilyadır.

Bu dönem, Louis XIV dönemindeki sarayın güçlü gösterişine tepki niteliğinde olan; geçmişin resmi ve törensel mekanlarının aksine, samimi küçük alanların evrimini ve dönemin kusursuz işçiliğini sergilemek üzere tasarlanmış zarif, kolay hareket ettirilebilir mobilyaları da beraberinde getirmiştir (Britannica, 2025).

Şekil 2. Wrought iron savonarola chair (A, URL-1, 2020, George III period satinwood work table (B, URL-2, 2020), Early 17th century Spanish walnut vargueno (C, URL-3, 2020), 19. Yüzyıl dikiş masası referanslı hazneli masa tasarımı (Tasarım: Aysu Kıyıcı).

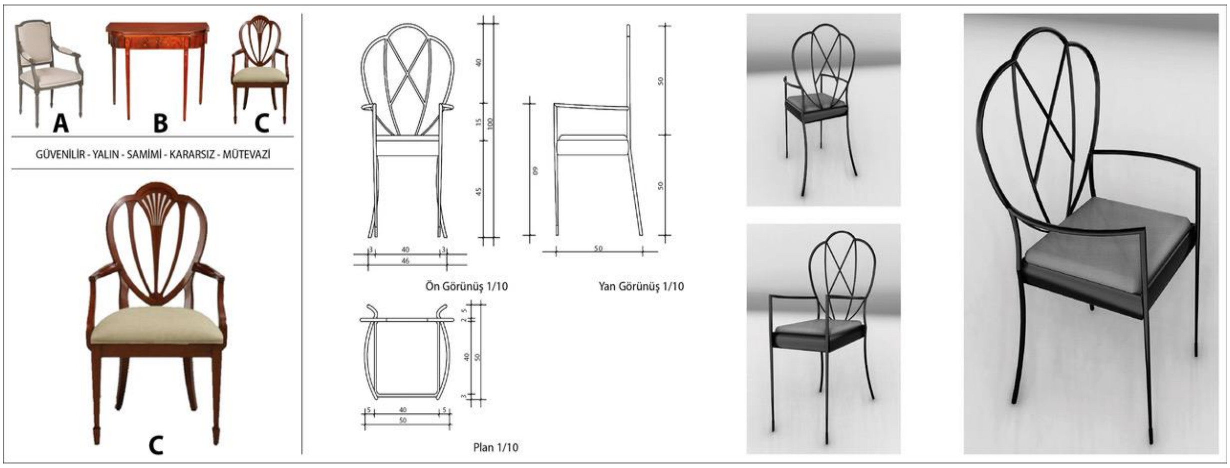
Yapılan anlamsal analizlerde, kaynak mobilyanın tedirginliği ve zarafeti korunması ve yeni tasarıma aktarılması gereken anlamsal nitelikler olarak belirlenmiştir. Bu sıfatları yansıtan ince, zemine doğru daha da incelen, uzun ayak yapısı ve benzer oranlı üst tabla korunmuştur. Hazne kısmı da yine genetik aktarımın en önemli öğelerinden biri olarak nitelendirilmiş ve korunmuştur. Öte yandan malzeme, günümüz koşullarında yerini ayaklarda çeliğe, üst tablada ise ahşap türevi bir levhaya (Yongalam veyahut MDFlam) bırakmıştır. Üst tabla formu da yeni mobilyada, kenarları yuvarlatılmış dörtgene dönüşmüştür. Hazne kısmı, gerek oranları, gerek plileri sembolize eden dikey çizgileri ile yine tekstil malzemeyle, ancak yarı geçirgen bir kumaşla yeni mobilyada yer almıştır. Renk, benzer karakteri ifade etmesi bakımından haznede yine beyaz tonlarında tutulmuş; diğer elemanlarda malzemeyle birlikte renk değişikliğine gidilmiştir.

Tarihsel süreçteki temel unsurlarını günümüz koşullarında taşımaya devam eden bu yeni tasarım; benzer biçimsel öğeler yanında, benzer karaktere de sahip bir alternatif niteliğindedir.

3.2 Tasarım 2 – Hepplewhite – Hepplewhite ruhu

Bir diğer tasarım, Güvenilir, Yalın, Samimi, Kararsız ve Mütevazı sıfatları ile yola başlamıştır. Belirlenen bu sıfatlar, İngiliz mobilya tarihinde 18. Yüzyıl'ın Üç Büyükleri olarak da bilinen tasarımcılardan biri olan George Hepplewhite'ın mobilya stilinde kendini bulmuştur. Kalp ve kalkan gibi arkalık modellerine sahip Hepplewhite mobilyaları, hafif ve seçkin olarak özetlenebilecektir. Esin kaynağı olarak alınan mobilya da masif ahşap malzeme ile üretilmiş; döşemeli oturağa sahip, kalp arkalıklı bir sandalyedir. Hafif ancak güçlü yapısı ve zarif kalp arkalığı imza niteliğindedir. Kolçaklardaki eğim, zarafet ve kullanım kolaylığını artırırken, içinde bulunulan dönemin inceliğine de atıf yapmaktadır (Şekil 3).

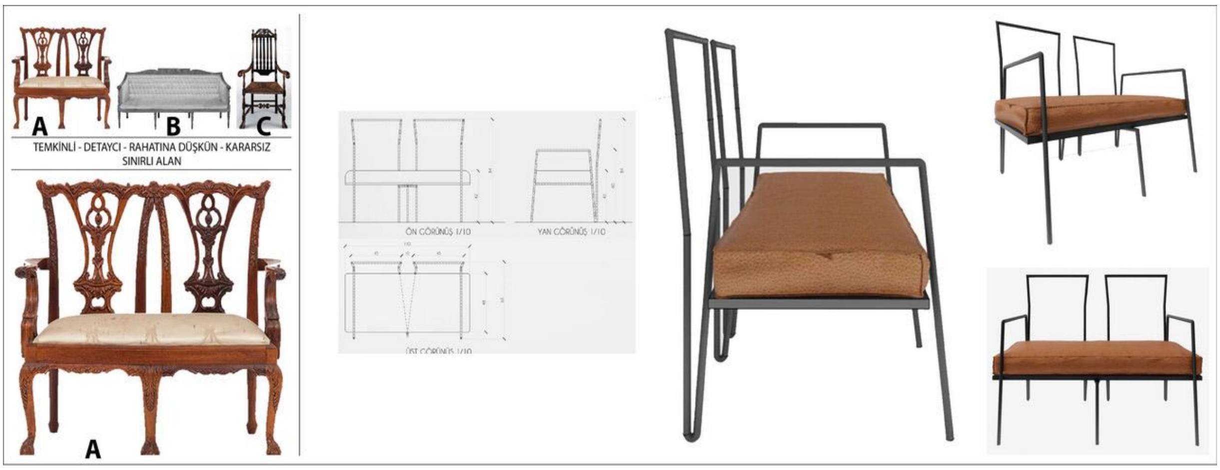
Yeni mobilyada, tasarım kodlarının belki de en baskını olan ve tarihsel aktarımda önemli bir referans olarak nitelendirilen kalp arkalık biçimi korunmuştur. Düz ön ayaklar ve arkaya eğimli arka ayaklar da dönemin ruhunu günümüze taşıyan en önemli simgelerden olmuştur. Döşemeli oturak, yeni tasarımda biçim değişikliğine uğrayarak yerini korumuştur. Asli bir öğe olarak görülen eğimli kolçaklar, yeni tasarımda da kalp arkalığın dikmesiyle kesişen noktada sonlanmaktadır ki, bu buluşma, silueti koruyan en önemli noktalardan biri konumundadır. Arkalık içi, kendine has, yeni biçimlerle tasarlanmıştır. Malzeme olarak siyah boyalı dökme demir seçilmiştir; ancak gelişen teknoloji ile benzer etki verilebilecek bir metal alaşımın da kullanılması mümkündür. Hepplewhite sandalyesinin, güvenilir, yalın ve mütevazı kimliği, yeni tasarımda da yaşamaya devam etmiştir. Yeni tasarım; önceki neslinden biraz daha soğuk, rafine ve mesafeli duruşuna rağmen, aynı zarafeti, hafifliği ve seçkinliği yansıtmaktadır.



Şekil 3. Louis arm chair-natural light linen (A, URL-4, 2020), Hepplewhite furniture plans (B, URL-5, 2020), Hepplewhite armchair (C, URL-6, 2020), 18. yüzyıl Hepplewhite kalp arkalıklı sandalye referanslı sandalye tasarımı (Tasarım: Burcu Örgen).

3.3 Tasarım 3 – Chippendale – Chippendale 5.0

Temkinli, Detaycı, Rahatına Düşkün ve Kararsız sıfatlarıyla çıkış noktası bulan bu tasarımın esin kaynağı Üç Büyükler'in ikincisi Thomas Chippendale'in çift sandalyesidir. 18. Yüzyıl İngiliz mobilyasının ve sonrasında dünya mobilya tarihinin en önemli isimlerden biri olan Chippendale'in mobilyalarında, genellikle Rokoko, Çin, Gotik gibi etkiler izlenebilir. Esin kaynağı olarak alınan mobilya, tipik Chippendale arkalıklı, döşemeli oturaklı, ön ayakları kabriyal yapıda, kolçaklı bir ikili sandalyedir. Önde, ortada üçüncü bir ayağın yer alması, tipik yapısal özelliklerden biridir. Temkinli ve rahatına düşkün yapı, sağlam gövdesinde izlenebilmektedir (Şekil 4).



Şekil 4. Mahogany chippendale double chair settle seat (A, URL-7, 2020), Sofa, north and central America, Massachusetts (B, URL-8, 2020), Banister-back armchair (C, URL-9, 2020), 18. Yüzyıl Chippendale çift sandalye referanslı ikili koltuk (Tasarımcı: Büşra Karaadam).

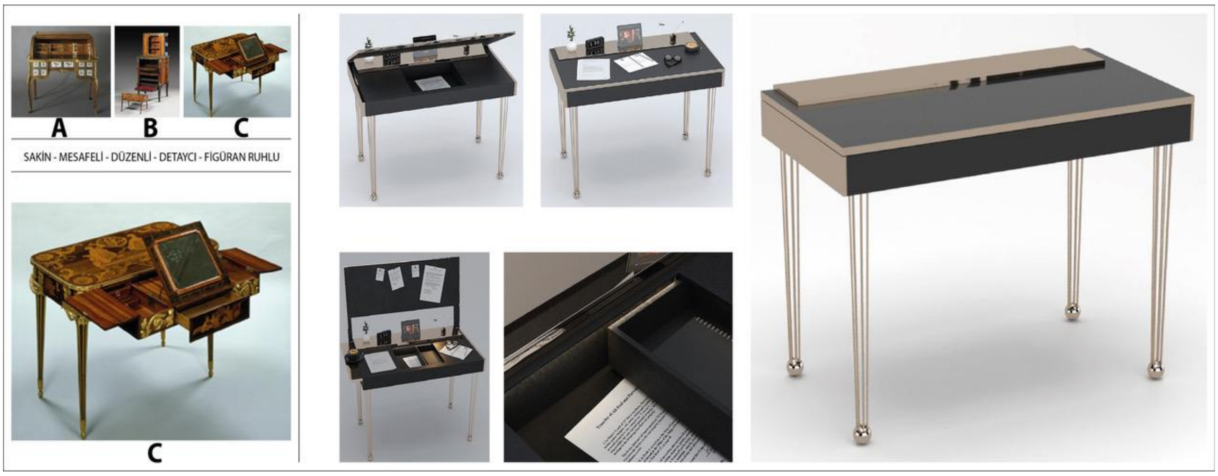
Yeni tasarım, esin kaynağının sağlam duruşunu, temkinini ve detaylarını barındırırken; yeni nesil olmanın gerektirdiği tüm değişimleri de özünü koruyarak geçirmiştir. Arkalıkların oturaktan ve dolayısıyla gövdeden ayrık konumlanması gibi zekice hamleleri bünyesinde barındıran bu tasarım, neslinden aldıklarını, günümüz teknolojisi ve yaratıcılığı ile birleştirmiş durumdadır. Yazarlarca, söz konusu yeni tasarıma "Chippendale 5.0" adının verilmesinin sebebi de bu altlıkta yatmaktadır.

Endüstri 5.0, endüstriyel sektördeki dönüşümü temsil etmektedir. Endüstri 4.0'ın dijitalleşme ve otomasyon odaklı yapısının ötesine geçerek; insanın yaratıcılığını, duygusal zekasını ve deneyimini teknolojiyle birleştiren yeni bir üretim paradigması öngörür (Entes, 2025).

Yeni tasarımda, ikili arkalık yapısı korunmakla birlikte, arkalık yalnızca genel geometrik yapıyı yansıtan bir kontur olarak yer almıştır. Arkalıkların üst köşelerindeki hafif dışa eğim, geçmişin izlerinin, kullanıma yönelik olmasa da saygıyla korunduğunu göstermektedir. Kaynak mobilyada birleşik olan bu iki arkalık, yeni tasarımda, yeni dünyada insanın bireyselliğini yansıtır şekilde ayrıdır. Kolçak, kaynak mobilyadaki çatkının aksine, ayakla birleşik bir yapıdadır. Arkalık ile de yalnızca arka ayağın zemine bastığı noktada temas etmektedir. Masif ağaç malzeme, yerini dökme demire bırakmıştır. Önceki nesilden aktarılan karakter özellikleri, muhafaza edilmesi gereken değerler misali korunmuş; işlevden ziyade sembolik olarak anlamsal boyutta yerini almıştır.

3.4 Tasarım 4 – yazı masası – çalışma masası

18. Yüzyıl'ın tipik yazı masa tipolojisini taşıyan bu yazı masası (Şekil 5), günümüzde kullanılabilecek bir çalışma masası tasarımına esin kaynağı olmuştur. Yola çıkılan sıfatlar, Sakin, Mesafeli, Düzenli, Detaycı ve Figüran Ruhlu olarak belirlenmiştir.



Şekil 5. Secrétaire à cylindre (A, URL-10, 2020), Burgundy table (B ve Mechanical table (C ve URL-11, 2020), 18. yüzyıl Jean-Henri Riesener yazı masası referanslı çalışma masası (Tasarımcı: Cansu Miraç Yıldırım).

Esin kaynağı olarak seçilen mobilyadaki mekanik özellikler ve bu sayede artırılan işlevsellik; yeni tasarıma da yansıtılmıştır. Kaynak mobilyanın vazgeçilmez unsurları olarak belirlenen açılır-kapanır ve katlanır mekanizmalar, yeni tasarımda farklı biçimlerde de olsa yer almıştır. Düz yapılı, zemine doğru incelen, yivli ayaklar, yeni tasarımda da korunmuştur ki, bu özellik de kaynak tasarıma karakterini veren en önemli niteliklerden biri olarak değerlendirilmiştir. Üst tabladaki kalınlık, depolama işlevinin korunmasına ek olarak, sakin ve düzenli karakterin temsillerinden biri olarak da yeni tasarımda aynı oranlarda yer almıştır.

Malzemenin kaynak mobilyaya verdiği sıcaklık, yeni tasarımda yerini daha soğuk bir etkiye bıraksa da mesafeli duruşun yansıtılması anlamında tasarımı güçlendirmiştir. Tarihsel referans, ayakların uçlarındaki topuzlar ile vurgulanmış; tasarımın diğer noktalarında tamamen güncel yaklaşımlar benimsenmiştir (Şekil 5).

3.5 Tasarım 5 – desk-on-frame – depolama ünitesi

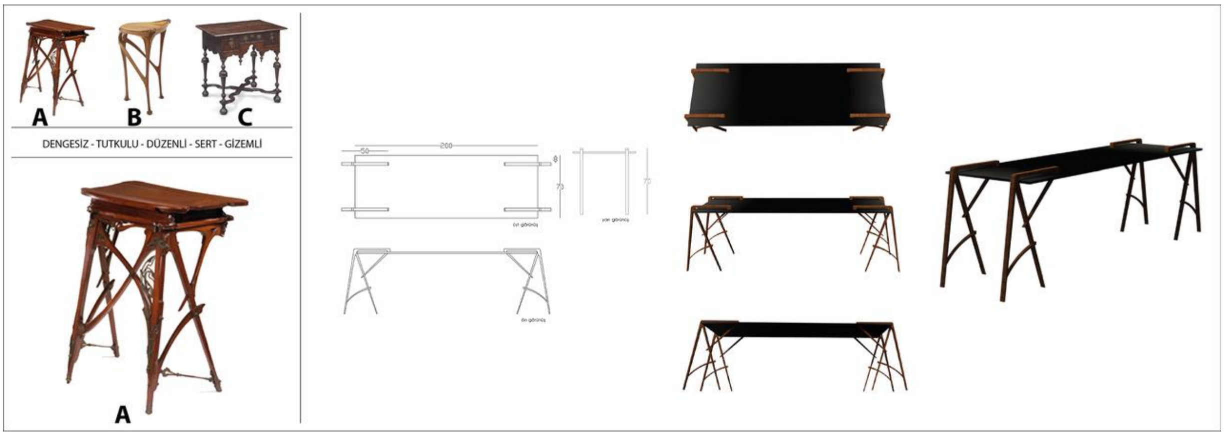
Şekil 6'da 19. Yüzyıl'ın tipik, depolamalı masalarından biri ve bu mobilya esin kaynağı alınarak tasarlanmış yeni mobilya yer almaktadır. Zarif, Kararsız, Sakin, İçe Dönük ve Rasyonel sıfatlarıyla başlanan süreçte, bu sıfatların bir kısmının esin kaynağı mobilyayı da tanımladığı anlaşılmıştır. Özellikle, zarafet, sakinlik, içe dönüklük ve rasyonalite, kaynak mobilyanın gerek genel geometrik yapısında gerekse yalın tavrında karşılık bulmuştur.

Şekil 6. Pair of Sheraton revival mahogany desk chairs mahogany 1890 (A, URL-12, 2020), Drop-leaf pembroke table (B, URL-13, 2020), Portable desk-on-frame table (C, URL-14, 2020), 19. yüzyıl başları, Amerikan desk-on-frame masa referanslı depolama ünitesi (Tasarımcı: İlkay Volkan Yüceer).

Gövdeye nazaran yüksek ve ince ayaklar sayesinde, üst kısımda yer alan masa ve depolama üniteleri oldukça zarif bir yapıya kavuşmuştur. Masa tablası içerisinde ve üzerinde yer alan kapalı kısımlarda içe dönüklük; bu alanların geometrik yapısında ise sakinlik ve rasyonellik okunmaktadır. Bu unsurlar, kaynak mobilyanın vazgeçilmez unsurları olarak, yeni tasarıma da aktarılmıştır. Geometrik yapı, yeni tasarımda genel hatlarıyla korunmuş olsa da üst kısma ek öğeler eklenmiş, yazı tablası incelmiş ve gövdeye entegre edilmiştir. Ayaklar, yeni tasarımda daha kısa olarak yer alsa da incelik ve zarafet anlamında niteliğini korumuştur. Ayak uçlarındaki yüksek metal kısımlar ise tarihsel öğelere referans vermektedir. Yapılan ince çerçeve kayıt gibi elamanlar sayesinde mobilya zarafetini de devam ettirmiştir. Yapılan eklemelerden biri olan deri kulp ise günümüz yaklaşımlarının da gözetildiğini sembolize etmekle birlikte, özündeki doğallığı koruyan bir görüntü sunmaktadır. Diğer malzeme farklılıkları ise depolama birimlerinde yapılmıştır. Kaynak mobilyadaki koyu renk, yerini beyaz tonlarına bırakmıştır. Herhangi bir renk, yani kroma girilmeyerek, sakin ve rasyonel yapı korunmuştur.

3.6 Tasarım 6 – Guimard desk – çalışma masası

Şekil 7'de, Hector Guimard'a ait Art Nouveau stilinde bir desk/masa ve buradan esinlenilerek tasarlanmış yeni bir çalışma masası yer almaktadır. Art Nouveau akımının önemli temsilcilerinden Guimard'ın seçilen mobilyasında, dönemin ve akımın neredeyse bütün tipik özellikleri izlenebilmektedir.

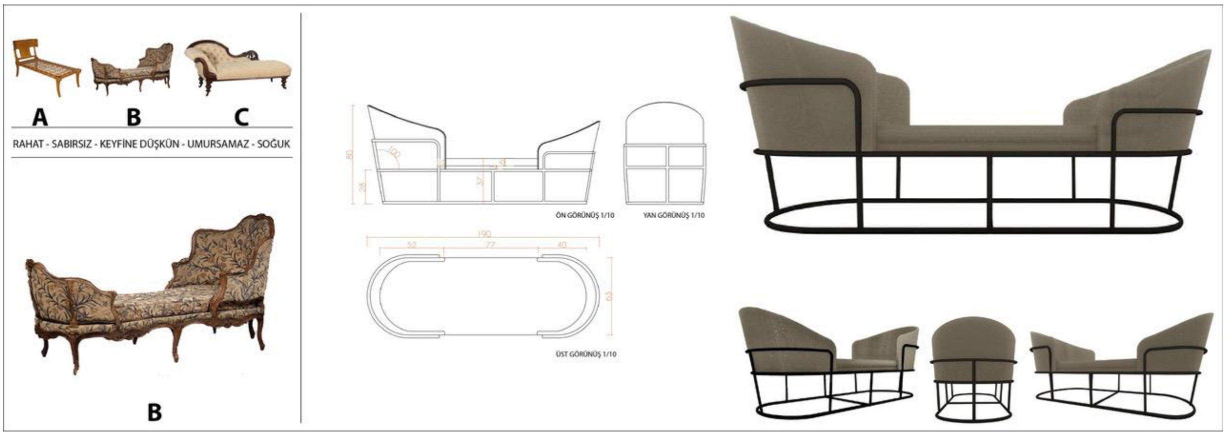


Şekil 7. Desk (A, URL-15, 2020), Side table (B, URL-16, 2020), William and Mary style walnut lowboy side table (C, URL-17, 2020), 19. yüzyıl sonları, Hector Guimard masa referanslı çalışma masası (Tasarımcı: Nahide Erol).

Dengesiz, Tutkulu, Düzenli, Sert ve Gizemli sıfatları ile yola çıkılan analizlerde, bu sıfatların bir kısmının esin kaynağı mobilya ile de örtüştüğü değerlendirilmiştir. Kaynak mobilyadaki dinamik denge, tutkulu floral öğeler, asimetrik detaylar ve gizem, yeni tasarım için de yol gösterici olmuştur. Art Nouveau stiline özgü floral biçimli öğeler ve zarafet, vazgeçilmez unsur olarak yeni tasarımda da yerini almıştır. Ancak, bu öğelerin birebir alınmasındansa, tarihsel aktarıma referans verecek detaylar, benzer oranlar ve benzer biçimleniş ilkeleriyle kullanılmıştır. Kaynak mobilyada küçük bir dikdörtgen biçiminde olan ve kayıttan boşlukla yükselen üst tabla, yeni tasarımda yerini ince tek bir levhaya bırakmıştır. Malzeme kaynak tasarımda masif ahşap iken, yeni tasarımda doğal ahşap kaplı yonga veya lif levha, masif ahşap veya metal alaşım ayak gibi güncel malzemeler kullanılabilecektir. Yeni tasarım, soyunun ve Art Nouveau karakterinin devamı niteliğinde, ancak tamamen yeni öğeler içeren bir örnek olarak değerlendirilmiştir.

3.7 Tasarım 7 – rokoko düşes – ikili koltuk

Yola Rahat, Sabırsız, Keyfine Düşkün, Umursamaz ve Soğuk sıfatlarıyla ile başlayan tasarımın esin kaynağı Rokoko stilinde bir düşes koltuk olarak seçilmiştir. Rahat, keyfine düşkün ve umursamaz sıfatlarının kaynak mobilyanın karakterinde belli oranda karşılık bulduğu söylenebilecektir (Şekil 8).



Şekil 8. "Klini" chaise (A, URL-18, 2020), Rare chaise longue en noyer richement sculpté, à dosserets e- Lot 320 (B, URL-19, 2020), Antique English Victorian mahogany upholstered chaise longue settee sofa couch (circa 1860) (C, URL-20, 2020), 19. yüzyıl rokoko düşes koltuk referanslı koltuk tasarımı (Tasarımcı: Sultan Gül).

Kaynak tasarımdaki karşılıklı ikili yapı, bu mobilyayı benzerlerinden ayıran ve karakterini önemli ölçüde etkileyen özelliklerdendir. Bir yanın diğerinden alçak olması da vazgeçilmez unsurlardan biri olarak nitelendirilmiştir. Rahatlığa vurgu yapan döşemeli yapı, bu özelliklerle birlikte, yeni tasarımda aynen korunmuştur. Ancak, kaynak mobilyada yer alan kabriyal ayak yapısı, yeni tasarımda yerini siyah boyalı boru profilden bir karkasa bırakmıştır. Döşemeli ana gövde, rahat, keyfine düşkün ve umursamaz karakterini bu yapıda da korumuştur. Arkalık eğimleriyle verilen Rokoko etkisi, tarihsel bir aktarım olarak, düşes tipolojisine destek olmak üzere yeni tasarımda da yer almıştır. Günümüz yaklaşımlarını içeren ancak, kaynak aldığı dönemin karakterini taşıyan bu mobilya, yapısal anlamda tamamen yeni öğeler barındıran, yeni bir mobilyadır.

Çalışmanın amacı, mobilya tasarımı bağlamında, esinlenme, tarihsel aktarım ve yenilik kavramlarını, retrospektif bir analiz ve prospektif bir sentez aracılığıyla irdelemektedir. Tasarımda, pek çok "şey" esin kaynağı olabilecektir. Bu kaynak kimi zaman tasarımcının öznel birikimine has bir öğe olabileceği gibi, kimi zaman bir kavram, kimi zaman bir sanat eseri, kimi zaman da başka bir tasarım olabilecektir. Burada önemli olan esinlenme ile kopyalama, taklit arasındaki sınırın belirlenmesidir. Esinlenme, ilerlemenin, yeni tasarımlar ortaya koymanın anahtarlarından biri iken, kopyalama ve taklit, tasarım alanını tamamen geriye götüren, tasarım etiğine ve hukukuna aykırı; kısa, orta veya uzun vadede doğrudan veya dolaylı paydaşlarına mutlak zarar getiren bir eylemdir. Bu zarar kimi zaman maddi, kimi zaman manevi, çoğu zaman ise hem maddi hem manevi olmaktadır. Bireysel zararların ötesinde, ülke kalkınması ve prestij anlamında da kayıplara neden olabilmektedir.

Kopyalama veya taklit anlamına gelmemekle birlikte, tarihsel süreçte karşımıza çıkan mobilyalara özgü öğeler, belirli analizler yapılmadan, ölçütler belirlenmeden de yeni tasarımlarda kullanılabilmektedir. Hatta klasik ve modern birleşimi mobilyalarda, anlamsal boyut göz önünde bulundurulmadan çeşitli tabirler kullanılabilmekte; tarihsel aktarımda tutarlılık ikinci plana atılabilmektedir. Oysa, mobilya tasarımında tarihsel referansların kullanılması, ancak ve ancak sağlam bilgi altyapısı, güçlü kavramsal altlık, analitik bir yaklaşım ve üsluplar arasında tutarlılığın sağlanması ile mümkün olabilecek bir eylemdir. Yeniliğin yakalanması ise bir başka hedef olarak karşımıza çıkar.

4 Sonuçlar ve Öneriler

Bu hedefler doğrultusunda, çalışmanın, yeni tasarımların geliştirilmesi veya geçmiş tasarımların doğru bir şekilde analiz edilebilmesi ve dolayısıyla tasarımlarda tutarlılığın sağlanabilmesine katkı sunması beklenmektedir.

Bu bağlamda, çalışmada aktarılan verilerden elde edilen sonuçlar ve bu sonuçlara bağlı olarak sunulmak istenen öneriler aşağıdaki gibidir:

- Mobilya tasarımında, tarihsel süreçte yer alan örnekler, yeni tasarımlar için esin kaynağı olabilecektir.
- Esinlenme ile kopyalama/taklit arasında çok belirgin bir ayrım bulunmaktadır. Esinlenme, tasarım geliştirmede önemli ve yararlı bir eylem iken; kopyalama ve taklit, tasarım etiğine ve hukukuna kesinlikle aykırı bir harekettir.
- Mobilya tasarımında, esin kaynağı tarihsel süreçten bir mobilya olarak alınacak ise, tarihsel sürece ve ilgili döneme/akıma hakim olunması son derece önemli ve zorunludur.
- Dönemlerin ve akımların, salt mobilyaların görünümleri üzerinden değerlendirilmesi, tasarımcıya çok sınırlı bir veri sunacaktır. Analizlerin, gerek işlevsel, gerek yapısal, gerekse anlamsal boyutlarda yapılması gerekmektedir.

- Esin kaynağı olarak alınan mobilyada yer alan unsurların, yeni tasarlanacak olan mobilyada ne şekilde yer alacağı; mobilyanın "yenilik" derecesini belirleyecektir. Bu sebeple, aktarımların dikkatle ve yine analiz bulgularına göre yapılması önem arz etmektedir.
- Esinlenme sonucunda, tarihsel aktarımlarda, biçimsel hiçbir öğeye yer vermemek de mümkündür. Karakter, her zaman salt biçimsel öğelerle yansıtılmak durumunda değildir. Kimi zaman yalnızca bir malzeme veya bir renk kullanımı da çok değerli ve yerinde referanslar oluşturabilecektir. Veyahut, esin kaynağı ile yeni tasarım arasında herhangi bir görsel benzerliğin olmadığı durumların da olması mümkündür. Önemli olan, yeni tasarımın, üzerine yükleneni iletebilmesi ve "yeni" olabilmesidir.

Yazar Katkıları

İsmail Bezci: Metodolojinin belirlenmesi, Görselleştirme, Makale Taslak oluşturma, Makale yazma ve düzenleme. **Vildan Dündar Türkkan:** Literatür taraması, Görselleştirme, Makale taslak oluşturma, Makale yazma ve düzenleme. **Gülçin Cankız Elibol**: Metodolojinin belirlenmesi, Makale taslak oluşturma, Makale yazma, inceleme ve düzenleme.

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Performance and deformation behavior of a master jig on circular saw machine using finite element method

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ABSTRACT: This study investigates the performance, stress distribution, deformation and potential failure modes of a newly developed Master Jig (MJ) designed for circular saw machine operations. The MJ comprises three components: the master jig body (MJB), the master jig accessories (MJA) and the master jig guide (MJG). The jig was modelled and simulated under applied static loads of 520 N and 600 N using SOLIDWORKS software. The MJ performance was evaluated, results were recorded, and a deformation graph was presented and shape displayed in true and defined scales of 0.135238 and 0.036047, respectively. The analysis shows that, maximum directional deformations at 520 N and 600 N were 8.463×10^2 mm and 3.197×10^3 mm respectively, elastic strains at 6.540 x 10 and 1.433 x 10, von mises stresses at 2.580×10^6 MPa and 3.930×10^7 MPa respectively, the Yield Strengths at 2.000×10^7 MPa and 3.930×10^7 MPa respectively, and the factor of safety at 31 and 11 respectively. The study underscores the potential of finite element modelling in the predictive design of woodworking jigs.

Keywords: Master Jig, Finite Element Modelling, Circular Saw Machine

Sonlu eleman yöntemleri kullanılarak dairesel testere makinesinde bir ana şablonun performans ve deformasyon davranışı

ÖZ: Bu çalışmada, dairesel testere tezgahı operasyonları için tasarlanmış yeni geliştirilmiş bir Ana Jig'in (MJ) performansı, gerilim dağılımı, deformasyonu ve potansiyel arıza modları araştırılmıştır. Geliştirilen MJ üç bileşenden oluşmaktadır: Ana Kalıp Gövdesi (MJB), Ana Kalıp Aksesuarları (MJA) ve Ana Kalıp Kılavuzu (MJG). MJ'nin modellenmesi, simülasyonu ve analizi için SOLIDWORKS yazılımı kullanılmış ve sırasıyla 520N ve 600N statik yükler uygulanmıştır. MJ'nin performansı değerlendirilmiş, sonuçlar kaydedilmiş, deformasyon grafiği sunulmuş ve şekli gerçek ve belirlenmiş ölçeklerde gösterilmiştir. Analizler, maksimum yönlendirilmiş deformasyonların sırasıyla 8.463×10^2 mm ve 3.197×10^3 mm, eşdeğer elastik şekil değişimlerinin 6.540×10^0 ve 1.433×10^1, von Mises gerilmelerinin 2.580×10^6 MPa ve 3.930×10^7 MPa, akma dayanımlarının 2.000×10^7 N/m² ve 3.930×10^7 N/m², güvenlik katsayısının ise sırasıyla 31 ve 11 olduğunu göstermektedir. Çalışma, ağaç işleme fikstürlerinin tahmini tasarımında sonlu elemanlar modellemesinin potansiyelini vurgulamaktadır.

Anahtar kelimeler: Ana Kalıp, Sonlu Eleman Metodu, Daire Testere Makinesi

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1. Introduction

The intricacies of predicting the performance and potential deformational behavior of wood and wood-based products have posed challenges that have, until now, relied heavily on intuition and experience (DeCristoforo, 1988; Okpala and Okechukwu, 2015; Massaro et al., 2023; Icha et al., 2024). Massive efforts have been made for several years to close the knowledge gap and enhance the techniques required to make wood more predictable (Falk and Itani, 1989; Brischke, 2021; Fiedler et al., 2023). Appraisal of the capacity of carpentry joints using Finite Element (FE) models had been investigated, compared to experimental results with acceptable prediction capacity (Massaro et al., 2022). Huber et al (2023) presented a technique based on X-ray computed tomography scans for recreating the structural features in wood boards. They suggest that eventually, using the technique for sawing logs could aid analyses of boards. Nailed connection in wood (Hong and Barrett, 2010), screws (Hu et al., 2022) crack propagation (Qiu et al., 2013), water absorption (Salin, 2008), wood fracture mechanics (Vasic, 2005), and many other behaviors have been presented (Blomqvist et al., 2023). Autengruber et al. (2021) developed a finite-element-based simulation approach to better understand the failure mechanics of wood-based composite and to support a targeted optimization of new cross-section types of I-joist beams. The performance of the modelling approach was reported as giving a very good prediction of stiffness values.

Frontini (2023) presented finite element models of wooden roofs with two main scenarios in an attempt to characterize the behavior of wooden connections in the diaphragm. The first scenario considered only the frame with line loads, while the second scenario considered that the wooden boards incorporating planks affected the performance of the structure. The result of their work agrees with the use of FEM to analyse, model and simulate the behaviors of wooden members. Blomqvist et al., (2023) created the FE model to study the bending process of a laminated veneer product. The veneers, which were modelled after the experimental ones with laminates of different thicknesses made of peeled veneers of European beech, had corresponding results. Zhong et al., (2021) simulated the deformation behavior of wood under axial and transverse compression conditions with representative volume elements (RVE). The simulation was able to reflect wood compression behavior from its results. This gives credits to the versatility and reliability of FEM as a tool for analysing and simulating the complex behaviors of wooden materials and structures under various conditions, thereby advancing both theoretical understanding and practical applications in wood material utilisation.

Woodworkers and engineers alike have learned that the performance and dependability of this essential component are not to be taken for granted. However, only big manufacturing organizations in developing nations have the expertise and resources to implement these contemporary technologies (Tankut et al., 2014). Thus, the Master jig's performance, as well as its potential deformation behavior, denote critical factors that directly affect the quality and safety of woodworking undertakings (Icha and Odey, 2024a; Fleming, 2020). Our study aims to address this by utilizing simulation and predictive modelling as effective methods for understanding the Master Jig's behavior in operation on the circular saw machine (Icha and Odey, 2024a; Autengruber, et al., 2021; Hernández et al., 2014). By using this novel approach, we hope to predict the jig's performance as well as solve the mystery of possible failure behaviors that have long evaded conventional techniques (Yıldırım et al., 2016; Autengruber, et al., 2021; Odey and Icha, 2022). Tradition and technology, craftsmanship and arithmetic, come together in this research. It is an investigation into how simulation and predictive modelling might improve our comprehension of the behavior of the Master Jig under various loads and situations. (Vasic et al., 2005; Tankut et al., 2014; Kumar et al., 2019).

Predicting the mechanical performance and deformation behavior of wood-based jigs remains a challenge, especially in environments where fabrication relies heavily on empirical methods (DeCristoforo, 1988; Icha et al., 2024). While materials such as solid wood and engineered boards have been widely used in jig fabrication, their layered anisotropic nature complicates accurate stress prediction without simulation tools. Prior studies using FEM have demonstrated promising results in understanding the behavior of woodworking component (Autengruber et al., 2021; Blomqvist et al., 2023). The master jig introduced in this study is designed to enhance both safety and precision during crosscutting and mitering operations amongst others on circular saw machines. Unlike previous jigs, this master jig integrates modular features to support local fabrication needs. This study presents the FEM- based simulation of the jig to evaluate its structural performance and identify potential deformation risk under operational loads.

2. Material and Method

2.1 Material

The materials used for this study were *Ochroma pyramidale* (Balsa) as solid wood and medium-density fiberboard (MDF) available within the environs of the research area (Calabar - Nigeria). A comprehensive detail of materials and hardware used in the construction of the master jig is detailed in Icha and Odey (2024b). Computer-aided design (CAD) was carried out using the SOLIDWORKS (2021) software interface to model the master jig. Detailed drawings are shown in Icha and Odey (2024b). The specific configurations of the master jig on the circular saw machine and direction of applied force are detailed in Fig. 1.

2.2 Finite element analysis

The SOLIDWORKS (2021) interface was used to model and simulate the MJ components. The MDF was approximated as a linear elastic isotropic material for baseline analysis. The mechanical properties of MDF, as listed in Table 1 (Hu et al., 2023), were specified for the FE model. Connection for the MJ was assigned as bolts and nuts as shown in Icha and Odey (2024b).

In this model, the base in the yz-plane is assigned a fixed geometry as an anchored point to resemble the experimental setup in Fig. 1. The jig was mounted on the circular saw table with fixed boundary conditions applied at contact points between the MJ and the saw table because the MJ's bar is slotted into the table's groove. A curvature-based mesher was employed using a minimum element size of 2 mm and 16 Jacobian points. The mesh quality, boundary conditions and loading points are shown in Fig. 3.

Loads of 520 N and 600 N were applied vertically to simulate the pressing force from a workpiece being guided by the MJ. These values were chosen based on empirical measurements of operator force during actual machine use (Fig. 1). The mesh comprised 134,792 nodes and 96,437 elements with average ratios below 1.8. This ensured high-resolution prediction of stress gradients across intricate corners and holes (Fig. 2).

Contact between jig components and the saw blade was defined using surface-to-surface contact with finite sliding and a friction coefficient of 0.33, consistent with Massaro and Malo (2020).

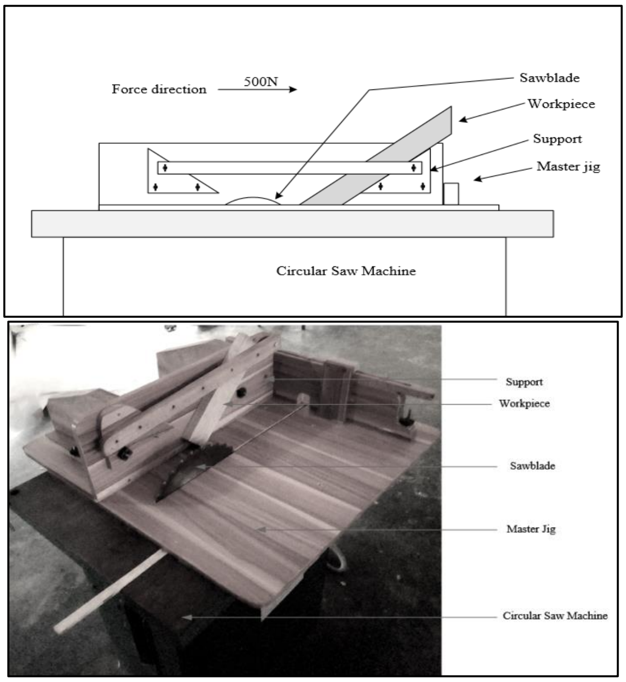

Figure 1. Experimental setup of the master jig on the circular saw machine

Table 1. Mechanical properties of MDF used in the study (Hu et al., 2023)

Property	Value	SI Units
Modulus of Elasticity	70,000	N/m^2
Poisson's Ratio	0.3	N/A
Tensile strength	0.61	N/mm^2
Yield strength	2e+07	N/m^2
Mass density	159.99	Kg/m^3
Shear modulus	3e+08	N/m^2

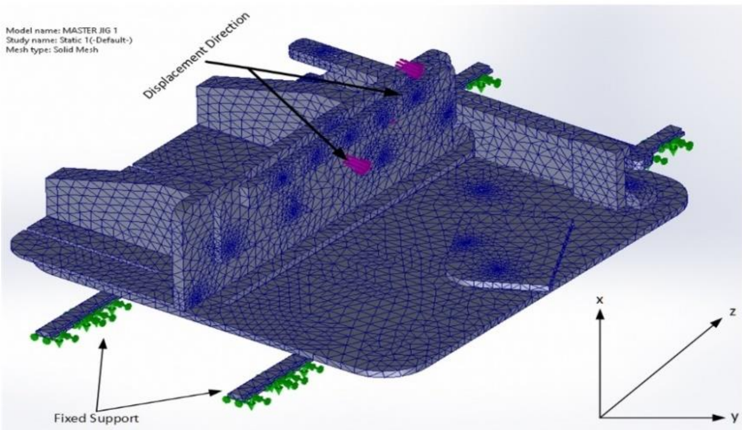

Figure 2. Mesh quality, boundary conditions and load points.

2.3 Failure criteria and equations

To evaluate the fractional behavior of the MJ under applied loads, established failure criteria were observed since materials undergo fraction when subjected to a sufficiently high load, with failure characteristics depending on the material properties and the mode of loading. In this study, varying loads of 520 and 600 N were applied on the MJ, the von Mises stress (equation 1), directional deformation (equation 2), Elastic strain (equation 3), yield stress (equation 4) and factor of safety (equation 5) were recorded (Yildirim et al., 2016). Two types of FE models were created to visualize the observed failure mode. The first represents the true scale of deformation, while the second was at a defined scale of 0.036047 and 0.135238, respectively.

Von Mises stress (σ_{vm})

$$\sigma_{vm} = \sqrt{\frac{1}{2}\left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2\right] + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)} \qquad (1)$$

Where: σ_x, σ_y, σ_z = Normal stresses in the x, y, and z directions, and τ_{xy}, τ_{yz}, τ_{zx} = Shear stresses in the respective planes

Directional deformation (Ui)

$$Ui = \frac{\sigma_i L}{E} \qquad (2)$$

Where: Ui = Deformation in direction i, σ_i = Stress in direction i, L = Initial length of the material, E = young's modulus

Elastic strain (ε_{vm})

$$\varepsilon_{vm} = \sqrt{\frac{1}{2}\left[(\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_y - \varepsilon_z)^2 + (\varepsilon_z - \varepsilon_x)^2\right] + \frac{3}{4}(\gamma_{xy}^2 + \gamma_{yz}^2 + \gamma_{zx}^2)} \qquad (3)$$

Where: ε_x, ε_y, ε_z = Normal strains in the x, y, and z directions, and γ_{xy}, γ_{yz}, γ_{zx} = Shear strains

Yield Stress (σ_y)

$$\sigma_y = \frac{F_y}{A} \qquad (4)$$

Where: σ_y = Yield stress, F_y = Yield force, A Cross-sectional area.

Factor of safety (FoS)

$$FoS = \frac{\sigma_y}{\sigma_{max}} \qquad (5)$$

Where: σ_y = Yield stress, σ_y = Maximum applied stress

3 Results and Discussion

3.1 Simulation analysis of the master jig

Table 2 presents data from the simulation analysis carried out on the modelled master jig when loads of 520 N and 600 N are applied, respectively. The von Mises static stress, elastic strain and deformation are presented at minimum and maximum levels. The yield strength and factor of safety are also presented in the table. The von Mises stress values of the master jig indicating the internal forces acting on the MJ, resulting from the external loads of 520N and 600N, ranged from 7.833 x 10^{-4} to 5.560 x 10^{5} MPa and 1.754 x 10^{6} to 9.436 x 10^{3} MPa, respectively. The elastic strain values of the master jig, which measures the ratio of deformation to the original length of the master jig and provides an indication of its elasticity, range from 2.083 x 10^{-8} to 6.540 x 10 MPa for the 520N and 6.572 x 10^{-8} to 1.433 x 10 for 600 N. The deformation values of the master jig, which indicate the amount by which the object deforms or changes shape in a particular direction, range from 0.000 x 10 mm to 8.463 x 10^{2} mm at 520N and 0.000 x 10 mm to 3.197 x 10^{3} mm at 600N. The yield strength of the master jig, which is the maximum stress it can withstand without permanent deformation at 520, was 2.000 x 10^{7} MPa and at 600N was 3.930 x 10^{7} MPa. The factor of safety associated with the master jig at 520N and 600N is 31 and 11, respectively. These results indicate that the master jig was much stronger compared to the expected load, making it safe.

Table 2. Simulation results: maximum and minimum load values

Object Name	Load (N)	von Mises Stress (Mpa)	Elastic Strain	Deformation (mm)	Yield Stress (Mpa)	Factor of Safety
Min	520	7.833 x 10^{-4}	2.083 x 10^{-8}	0.0	2.000 x 10^{7}	31
Max		5.560 x 10^{5}	6.540 x 10	8.463 x 10^{2}		
Min	600	1.754 x 10^{6}	6.572 x 10^{-8}	0.0	3.930 x 10^{7}	11
Max		9.436 x 10^{-3}	1.433x 10	3.197x 10^{3}		

3.2 Simulation of distribution diagrams

Figs. 3 and 4 show the schematic distribution diagrams for von Mises stresses (a), elastic strain (b), and displacement (c) at 600N and 520N, respectively.

At the external load of 520N, the von Mises stresses (σ_{vm}) are observed to be higher at the stop where the force is directed and the work piece is wedged, the base slot and the lower parts of the fence. Other areas were observed to have minimal stress distribution levels. The elastic strain (ε_{vm}) distribution at the same loading condition appears to affect the same areas where the stress distributions were displaced at almost the same prominence with minimal levels of stress distribution in other areas. The displacement distribution (Ui) is observed to be highest at the point of interaction with the saw blade at over 8.463 x 10^{+2} mm varying as it moves away from the stop on both sides within the range of 5.078 x 10^{+2} mm to 8.463 x 10^{+1} mm, leaving an even distribution on other sides of the base as low as and below 1.000 x 10^{-30} mm.

At an external load of 600N, the von Mises stresses (σ_{vm}) are observed to be higher at the vertical support where the force is directed and the workpiece is wedged, the base slot and the lower parts of the fence. Other areas were observed to have minimal stress distribution levels. The elastic strain (ε_{vm}) distribution at the same loading condition appears to affect the same areas where the stress distributions were displaced, but with more prominence with minimal levels of stress distribution were observed in other areas. The displacement distribution (*Ui*) is observed to be highest at the upper part of the vertical support at over 3.197 x 10^{+3} mm varying as it moves towards the fence and fence bracers on both sides within the range of 9.394 x 10^{+2} mm to 2.238 x 10^{+3} mm, leaving an even distribution on other sides of the base as low as and below 1.000 x 10^{-30} mm.

These results indicate that the MJ exhibited stress concentrations at vertical supports and fence junctions, where the workpiece pressure is highest. Maximum directional deformations occurred at the point of saw contact, confirming the structural demand in that area.

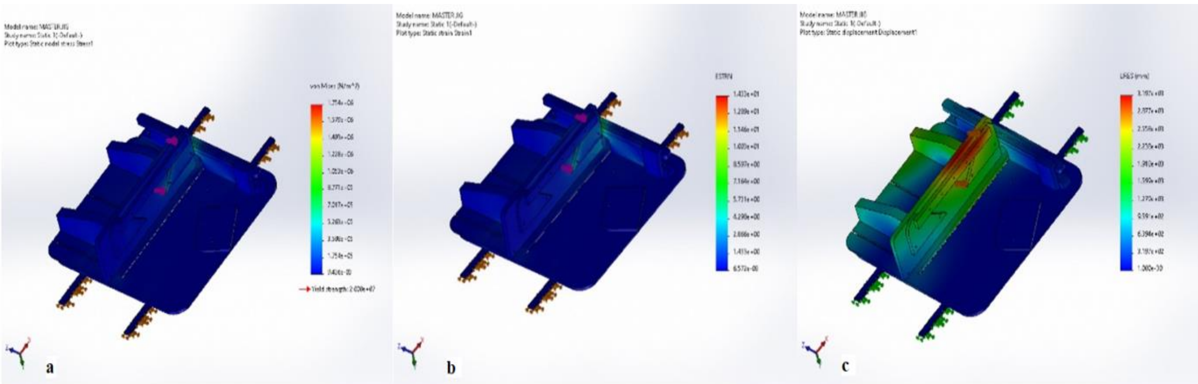

Figure 3. Distribution of von Mises stress (a), Elastic strain (b) and Displacement (c) with applied external load at 600 N

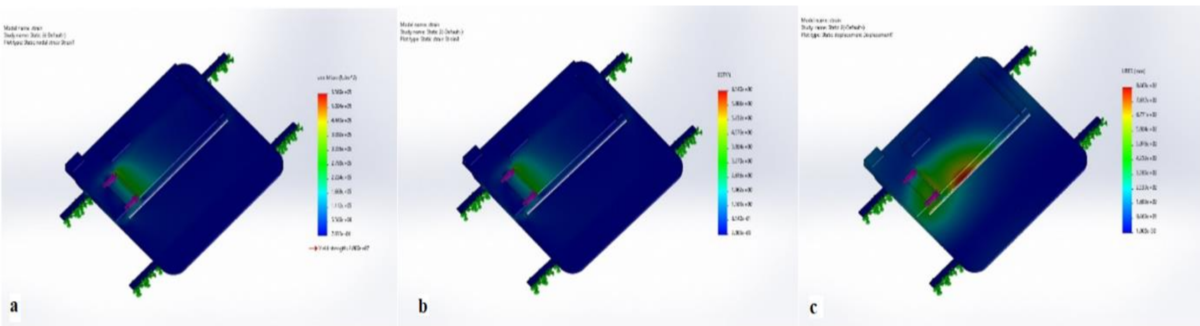

Figure 4. Distribution of von Mises stress (a), elestic strain (b) and displacement (c) with applied external load at 520 N

3.3 Factor of safety

Fig. 5a and b. shows the factor of safety value on the simulated FE model when external loads of 520N and 600N are applied. The high factor of safety (11 and 31) across both load cases confirms the jig's structural resilience and suitability for high-force cutting applications, which means that the master jig, as designed, can withstand loads that are 11 and 31 times higher than its designed load.

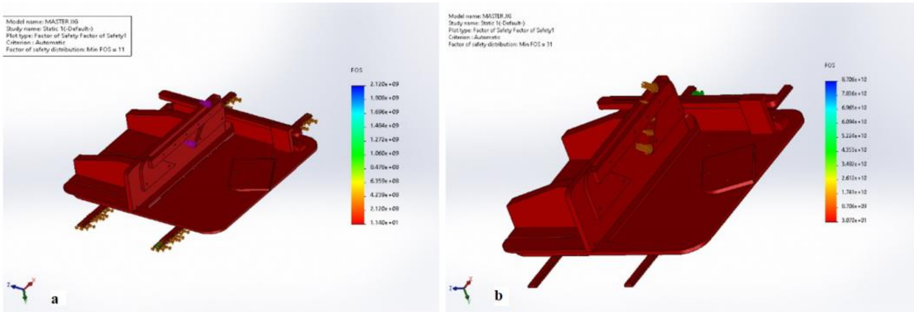

Figure 5. Factor of Safety at 520N (a) and 600N (b)

3.4 Deformation behaviour

To observe the deformation behavior (failure mode) of the FE modelled master jig at 520N and 600N applied load, the stress, strain and displacement diagram were scaled to 0.135238 and 0.036047, respectively which allows visualisation of potential failure regions. The displays shown in Figs. 6a, b, c and 7a, b, c respectively are results of localised deformation in high-stress zones, validating the design's robustness for typical woodworking forces. However, it should be noted that the true scale (Figs. 3 and 4) represents the possible deformation that can occur on the jig.

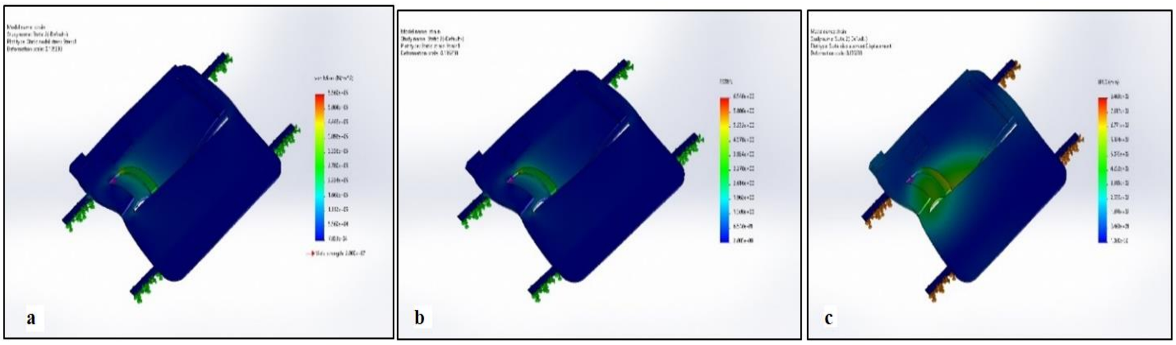

Figure 6. Deformation behavior of FE model (a) stress, (b) Strain, and (c) displacement when scaled to 0.135238 for 520N

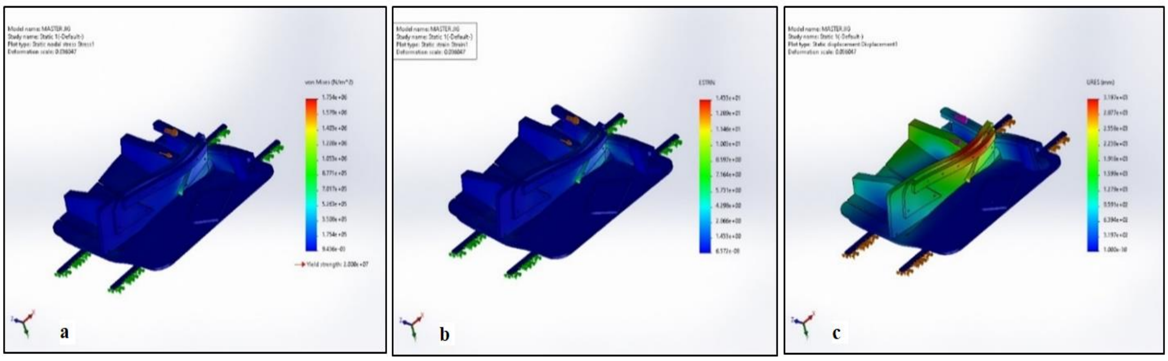

Figure 7. Deformation behavior of FE model (a) stress, (b) Strain, and (c) displacement when scaled to 0.036047 for 600N

3.5 Nodal edge plots

Fig. 8 (a-c) presents the nodal edge graph (plots) of static stress, strain and displacement along a parametric distance for the vertical work support face, respectively. The von Mises stress values decreased from 4.00 MPa to 1.00 MPa, suggesting a reduction in the stress along the parametric distance (Fig. 8a). The strain contour starts at minimum (0.00), indicating no deformation at the beginning of the parametric distance and jumps significantly to 5.00 and then to 10.00, suggesting a rapid increase in the strain over a short distance. It then decreases gradually, suggesting that the material experienced less deformation as the parametric distance increased beyond the critical point (Fig. 8b). The displacement contour starts at 1,500.00 mm and increases steadily as the distance increases, indicating a movement away from the point of maximum displacement. Table 3 presents the sum, average, maximum, minimum and root square means of the nodal edge plots for the vertical work support face.

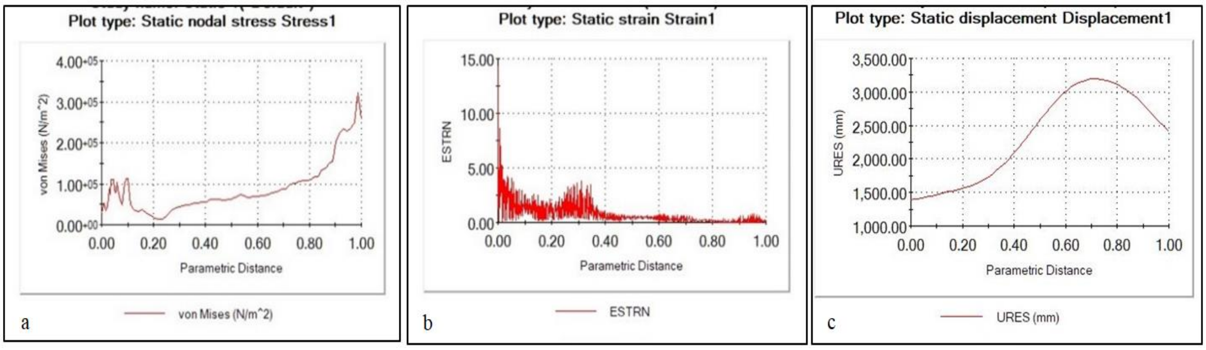

Figure 8. Static stress (a), strain (b) and Displacement (c) for the Vertical Work Support face

Fig. 9 (a-c) presents the nodal edge graph (plots) of static stress, strain and displacement along a parametric distance for the left and right vertical mitre, respectively. The von Mises stress starts at nearly 1.5 10^5 MPa with slight fluctuation around the middle area, then increasing significantly towards the end of the parametric distance. This suggests a possible stress concentration at the left and right vertical mitre (Fig. 11a). The static strain (ESTRN) plot (Fig. 9b) starts at nearly 2.00 with a slight increase and fluctuations in the middle area, and a significant spike is observed towards the tail of the parametric distance near 8.0. This sharp increase towards the end may indicate a region of high deformation, possibly near the concentration point of the L/R vertical mitre. For the displacement (Fig. 9c), an initial decrease near the minimum was observed at the parameter distance of 0.1. Afterwards, a near-linear trend is observed as the displacement gradually increases until its peak at approximately 3000 mm and a parametric distance of 1.0. The sum, average, maximum, minimum and root square means of the nodal edge plots for the left and right vertical mitre are presented in Table 3.

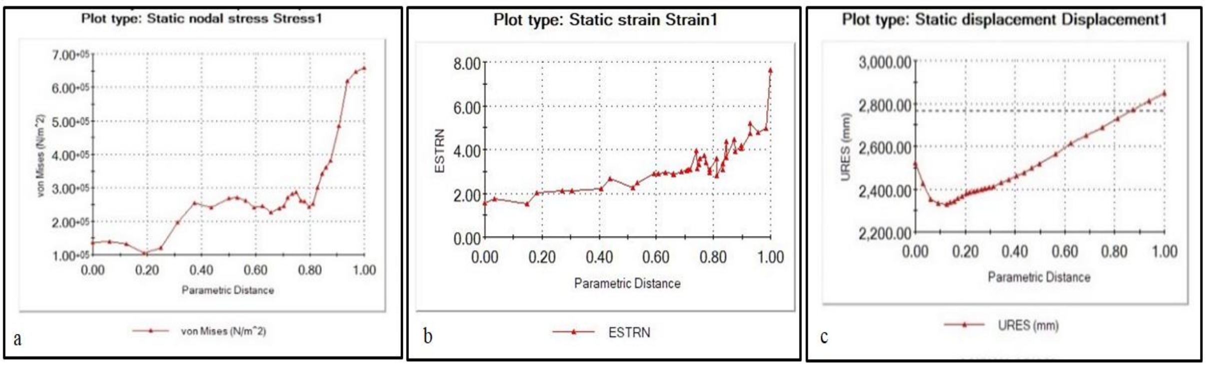

Figure 9. Static stress, strain and Displacement for the Left and Right Vertical mitre

Fig. 10 (a-c) presents the nodal edge graph (plots) of static stress, strain and displacement along a parametric distance for the adjustable stop bar, respectively. The static Nodal stress (von Mises stress) distribution contour starts very low (Fig. 10a), beginning from a 0.00-0.05 parametric distance and then moves sharply to a peak of about 9.00 Mpa in the meddle indicating a critical stress concentration and quickly drops down before getting to the end of the parametric distance of the adjustable bar. The static strain (ESTRN) plot has similar distributions to the von Mises stress (Fig. 10b). However, the static displacement (URES) distribution moderates its initial displacement from approximately 700 mm, undulating to the maximum displacement at a peak of above 1000 mm at the mid-region, and then decreasing gradually until the contour hits the flow at nearly 1.0 parametric distance. The sum, average, maximum, minimum and root square means of adjustable stop bar are presented in Table 3.

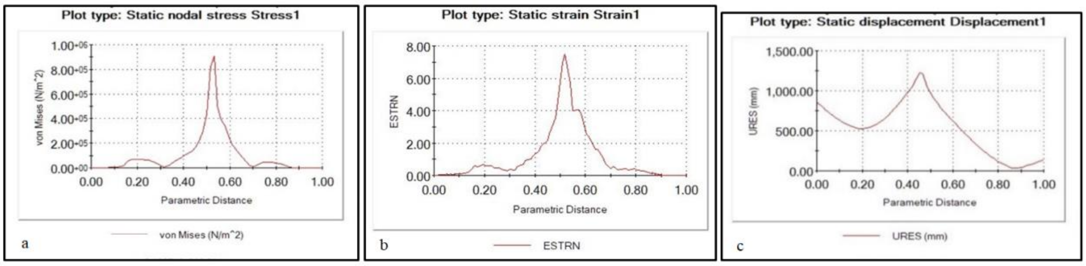

Figure 10. Static stress, strain and Displacement for the Adjustable Stop Bar

Table 3. Results based-on static nodal edge plots for simulation of different components

Object Name	von Mises Stress (MPa)	Elastic Strain	Resultant Displacement (mm)
Vertical Work Support face			
Sum	7.522×10^{6}	1.533×10^{3}	1.785×10^{5}
Average	8.646×10^{4}	8.706×10^{-1}	2.318×10^{3}
Maximum	3.221×10^{5}	1.433×10^{4}	3.197×10^{3}
Minimum	1.346×10^{4}	8.145×10^{-3}	1.385×10^{3}
RSM	1.0486×10^{-5}	1.370 x 100	2.403×10^{3}
Left and Right Vertical mitre			
Sum	8.975×10^{6}	1.393×10^{2}	7.703×10^{4}
Average	2.895×10^{5}	3.316 x 10	2.485×10^{3}
Maximum	6.576×10^{5}	7.632 x 10	2.848×10^{3}
Minimum	1.036×10^{5}	1.497 x 10	2.330×10^{3}
RSM	3.209×10^{-5}	3.499 x 10	2.489×10^{3}
Adjustable Stop Bar			
Sum	6.571×10^{6}	7.487×10^{1}	4.145×10^{4}
Average	8.113×10^{4}	6.568×10^{-1}	5.117×10^{3}
Maximum	9.089×10^{5}	7.792 x 10	1.223×10^{3}
Minimum	9.762 x 10	1.290×10^{4}	3.098×10^{1}
RSM	1.805×10^{-5}	1.508 x 10	6.109×10^{2}

4 Conclusions

A finite element-based approach was used to investigate the performance and deformation behaviour of the master jig on the circular saw machine as presented in this study. The following conclusions are drawn:

- The study confirms the suitability of FEM in evaluating the structural performance of a master jig for circular saw operations.
- The isotropic material assumptions provided an acceptable first-order prediction.
- The jig's performance under 520 N and 600 N loads suggest its effective use in real woodworking operations.

Future works should focus on incorporating anisotropic multi-layered MDF modelling for higher fidelity and developing additional jig types for varied cutting tasks using this modelling framework.

Author Contributions

Asibong Asibong Icha: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, **Simon Ogbeche Odey**: Funding acquisition, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest statement

The authors declare no conflict of interest.

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Performance properties of heat treated and reinforced laminated veneer lumber with glass fiber

Osman Perçin[1]*

ABSTRACT: In this study, some technological properties of test samples manufactured from heat-treated scotch pine (*Pinus sylvestris* L.) wood were analyzed. For this aim, experimental specimens were manufactured from heat-treated material at temperatures of 140 °C, 160 °C, 180 °C and 200 °C for 3 hours. Three different experimental groups were prepared from the sapwood of the log. The first group was massive wood (wood), the second group was laminated veneer lumber (LVL), and the third group was reinforced laminated veneer lumber (RLVL) using glass fiber fabric. One-component polyurethane based adhesive was used as a binder in this study. Air-dry density, equilibrium moisture content (EMC), and compressive strength parallel to the grain were determined to analyze the effects of the reinforcement on the LVL composite. Test results showed that reinforced heat-treated LVL samples with glass fibers increased both air dry density and compressive strength parallel to the grain. On the other hand, the EMC values of the test samples decreased with increasing heat treatment temperature and reinforcement process. Improving the some physical and mechanical properties of heat-treated wood material can contribute to the widespread use in buildings.

Keywords: Reinforcement, Glass Fiber, Mechanical Properties, Physical Properties

Isıl işlem uygulanmış ve cam elyaf ile güçlendirme yapılmış lamine kaplama kerestenin performans özellikleri

ÖZ: Bu çalışmada, ısıl işlem uygulanmış sarıçam (*Pinus sylvestris* L.) odunundan hazırlanan deney örneklerinin bazı teknolojik özellikleri analiz edilmiştir. Bu amaçla, 140 °C, 160 °C, 180 °C ve 200 °C'de 3 saat süre ısıl işleme tabi tutulan malzemelerden deney örnekleri üretilmiştir. Tomruğun diri odun kısmından üç farklı deney grubu hazırlanmıştır. Birinci grup masif ahşap (ahşap), ikinci grup lamine kaplama kereste (LVL) ve üçüncü grup ise cam elyaf kumaş kullanılarak güçlendirilmiş lamine kaplama kerestedir (RLVL). Bu çalışmada tutkal olarak tek bileşenli poliüretan bazlı yapıştırıcı kullanılmıştır. Takviyenin LVL kompozit üzerindeki etkilerini analiz etmek için hava kuru yoğunluk, denge rutubet miktarı (EMC) ve liflere paralel basınç direnci değerleri belirlenmiştir. Deney sonuçları, ısıl işlem uygulanmış ve cam elyaf ile güçlendirilmiş LVL numunelerinin hava kurusu yoğunluk ve liflere paralel basınç direncini artırdığını göstermektedir. Öte yandan, deney örneklerinin EMC değerleri uygulanan ısıl işlem sıcaklıklarına ve yapılan güçlenndirme işlemine bağlı olarak azalmıştır. Isıl işlem uygulanmış ahşap malzemenin fiziksel ve mekanik özelliklerinin geliştirilmesi binalarda uygun alanlarda kullanımının yaygınlaşmasına katkı sağlayabilir.

Keywords: Güçlendirme, Cam Elyaf, Mekanik Özellikler, Fiziksel Özellikler

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1 Introduction

Wood has been widely used in the building and construction industry for a long time due to its low density but high mechanical properties, good insulation properties, environmentally friendly material and sustainability, easy availability and aesthetic appeal. In addition to these superior properties, wood reduces energy consumption during construction, has lower embodied energy compared to building materials such as steel and concrete, and is a building material that has a significant effect on reducing the carbon footprint of buildings (Wimmers, 2017; Zhang et al., 2020; Dukarska and Mirski, 2023). Due to these positive features, it is commonly used in indoor and outdoor decorations, and also, knowing the properties of wood can lead to its effective and efficient use in relevant areas (Yeşil et al. 2021; Uzun and Sarıkahya, 2021; Bacak and Yaldız, 2023; Oral, 2023).

Nowadays, the need for housing is rapidly increasing all over the world. Factors such as the decrease in natural forest resources, the inadequacy of existing natural resources to meet the demand for wood materials, natural disasters (forest fire, landslide), the unavailability of wood materials in sufficient quantities, and the incorrect and unconscious use of forest resources have made it necessary to develop new alternative wood products. Initiatives and efforts for the efficient and effective use of wood materials have visibly increased in recent years. The need for more efficient and effective use of wood materials and the improvement of their properties has led to the formation of demand for structural products with different properties. The use of wood in building construction is limited due to cracking and the tendency of the fibers to bend, and it can be difficult to obtain the right shapes for use. In addition, wood material has some undesirable properties such as structural cracks, knots, growth stress and limited length. This situation encouraged the development of wood-based structural composite materials (Mengeloğlu and Kurt, 2004; Çavuş et al., 2013).

Wood and wood-based composite structural materials have been commonly used in the construction and furniture industry from the past to the present due to their attractive features such as good aesthetic appearance, natural and sustainable materials, cheap and easy processing compared to other building materials. Wood-based composite materials are mostly preferred as an alternative to massive wood in structural applications bacause they offer better dimensional stability and durability properties (Shi and Walker, 2006; Bekhta et al., 2021). One of the wood-based composites widely used in the woodworking industry is LVL composite material. In some applications, wood-based composites are used as an alternative to other building materials such as iron, steel and concrete because they meet high mechanical requirements despite their low weight. There are factors arising from production technologies such as pressing time, pressing temperature, and pressing pressure that affect the quality and some properties of wood-based structural composites. In addition, other factors such as the wood species, the type of adhesive, veneer thickness and the layer structure are also effective in the properties of wood-based composite (Auriga et al., 2020).

The use of LVL, one of the important structural wood-based composites, is steadily increasing in the woodworking industry. The mechanical performance, dimensional stability, and the ability to be produced in the required sizes have made it an attractive material for structural applications. Today, reinforcement technology is considered an applicable and effective method for improving the mechanical properties of LVLs made of low-quality, fast-growing wood (Wang et al., 2015).

Fiber reinforced plastics (FRP) are composite materials made from polymer resins as matrix and glass or carbon fibers as reinforcement. Due to their lightweight, high strength, good corrosion resistance, and flexibility in design FRP materials are commonly usage in different sectors such as civil construction, aerospace, shipbuilding, automobile, etc. In recent years, the intense interest in advanced composite materials has encouraged the development of polymer composites (Tan and Pillai, 2010). Fiber-reinforced polymers (FRP) have been used effectively for decades to maintain structural integrity and increase strength thanks to their many advantageous properties. Due to its strength properties, this material is preferred for all types of reinforcement and support connections in areas such as restoration applications, I-beam production, bridge decking, wooden beams and columns. Furthermore, FRP reinforcement has the potential to increase the flexural stiffness and ultimate bearing capacity of timber beams (Karaman, 2025). Fiber-reinforced polymer (FRP) composites such as E-glass FRP, carbon FRP, and aramid FRP (AFRP) are commonly used as reinforcement materials to improve the physical and mechanical properties of wood and wood-based composites (Karaman et al., 2021).

In recent years, solid wood and wood-based materials have been widely used in many areas due to their structural properties. Wood materials attract attention as one of the most versatile and sustainable building materials in terms of their favorable properties. Because wood is a natural material, it can be easily damaged by fungi and insects. In addition, its volumes change due to moisture adsorption and desorption properties. These are negative properties that can limit the effective use of wood material in some building applications. Due to heat treatment, the biological durability of wood material increased and dimensional stability is achieved (Korkut and Budakcı, 2010).

Heat treatment, an environmentally friendly wood treatment method, is an effective alternative process for improving certain properties of wood without the use of chemicals (Johansson, 2008). Depending on the heat treatment conditions applied, there are changes in the properties of the wood material. Depending on the temperature, the biological durability of the wood material improves. On the other hand, heat treatment applied at high temperatures decreases the mechanical properties of the wood material. Heat treatment applied at high temperatures increases the brittleness of the wood material and weakens the mechanical properties. Decreases in mechanical strengths adversely affect the use of heat-treated wood material as a load-bearing system in buildings (Jamsa and Viitaniemi, 2001). Bekhta and Niemz (2003) observed a decrease between 4-9% in modulus of elasticity and about 44–50% of bending strength in Norway spruce wood heat-treated at 200 °C for 2 and 24 hours. Likewise, Gunduz et al., (2009) affirmed that the compression strength of Hornbeam *(Carpinus betulus)* wood approximately decreased by 30%.

In previous studies, the mechanical properties of heat-treated wood materials were analyzed in detail, and it was determined that the mechanical properties were negatively affected and decreased (Yildiz et al., 2006; Shi et al., 2007). The technologies used in fiber production are constantly improving, and this is considered as an effective method that offers significant opportunities to improve the properties of wood materials with low quality and mechanical properties. The use of wood materials with low quality and poor mechanical properties is limited, especially in load-bearing systems. Strengthening wood materials with different methods can contribute to their widespread use. In this respect, reinforced laminated veneer lumber can be an alternative to solid wood with high quality and high mechanical properties (Wang et al., 2015). The present study is aimed to determine the effect of the additions of plain weave glass fibers between wood layers bonded with polyurethane (PU) resin on density, equilibrium moisture content, and compressive strength parallel to the grain of the manufactured panels using heat-treated scotch pine (*Pinus sylvestris* L.) veneers.

2 Materials and Methods

2.1 Materials

Scotch pine (*Pinus sylvestris* L.) wood, commonly used in furniture and woodworking industries, was chosen as test material in this study. Scotch pine wood material has been preferred because it is widely available in our country and is widely used industrially. The wood material was obtained by purchasing it from the sawmill in an air-dry condition. The preparation of the test specimens was carried out according to the principles of TS 2470 (1976). The draft timbers from which the test samples will be prepared are without any defects and are properly grown timbers. After purchasing the wooden panels, they were cut into 6 x 75 x 450 cm (tangential x radial x longitudinal) dimensions and prepared for heat treatment. The cut draft boards were conditioned at 20 ±2°C and 65 ±5% relative humidity before heat treatment.

Glass fiber fabric can be produced in different weights. The glass fiber fabrics used in this study were supplied by Dost Kimya company. The glass fiber fabrics have a plain weave type and a weight of 200 g/m^2. Materials used in experiments are given in Figure 1.

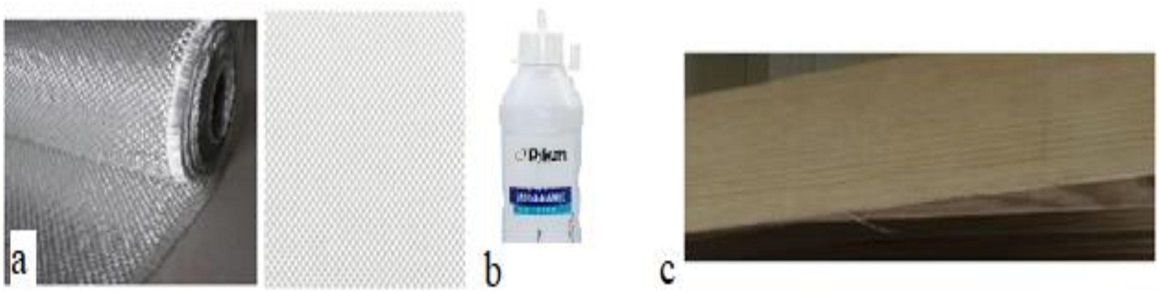

Figure 1. Materials used in experiments (a: plain woven glass fiber, b: adhesive, c: wood veneer)

In this study, one component polyurethane adhesive (Marin&Marin) (Polisan) was used as a binder because it is commonly used in the woodworking and furniture industries. The density properties of the adhesive used are 1.11 g/cm^3, viscosity 3000–5500 cps, pH = 7.0, and amount of use 180-200 g/m^2.

2.2 Method

Afterwards, draft boards that reached equilibrium moisture in the air conditioning cabin, heat treatment was applied to the specimens at 140 °C, 160 °C, 180 °C, and 200 °C for 3 h under atmospheric pressure. After heat-treatment, all wood panels were cut into 4 x 75 x 450 cm (tangential x radial x longitudinal) dimensions by using a circular saw machine, subsequently heat-treated and non-heat-treated specimens were conditioned at 20 ± 2 °C with 65 ± 5% relative humidity according to TS 642 (1997) in air conditioning cabinet.

LVL test specimens produced within the scope of this study consist of 5-layer wood material, while RLVL test specimens consist of 5-layer wood veneers and glass fiber placed between them according to TS EN 386 (1999) (Figure 2).

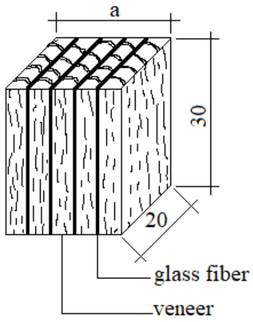

Figure 2. Combination of reinforced LVL samples (mm)

In the production of the test specimens, the adhesive was applied to the veneer surfaces with a brush. Approximately 180 g/m^2 of adhesive was applied between two wood veneers. Approximately 300 g/m^2 was applied between the glass fiber fabric and wood veneer due to the surface properties. The pressing of the composite materials was carried out in a hydraulic press. In the pressing process, the pressure was set to 0.9 N/mm^2, the press time was 200 minutes, and the press temperature was set to 25 °C. The draft composite sheets were kept for about 7 days for full curing process after pressing. After this process, 5 mm was cut from the edges of the LVL and RLVL draft sheets. Then, wood, LVL and RLVL test specimens were produced from these draft materials. The wood and composite specimens were conditioned at 20±2°C and 65±5% relative humidity for at least two weeks. The compressive strength parallel to the grain, density and equilibrium moisture content (EMC) were tested based on the TS 2595 (1997), TS 2472 (1976), and TS 2471 (1976) standards, respectively. The dimensions of the test samples used in the experiments are a x 20 x 30 mm (thickness, width, length). Ten test specimens were prepared for each group in this study. The thicknesses of the test samples were approximately average between 19.98-20.04 mm for wood, approximately average between 20.11-20.43 mm for LVL, and approximately average between 20.51-21.07 mm for RLVL samples. Compressive tests were performed using a Universal Test Machine (Instron-5969) with a 4 mm/min loading speed. Compressive strength parallel to the grain test setup and test samples is given in Figure 3.

Figure 3. Compressive strength parallel to the grain test setup and test samples

1.3. Statistical analyses

The MSTAT-C statistical program was used in statistical evaluations. Variance analysis (ANOVA) was applied, and when the difference between the groups in the data was significant, the difference between the mean values was compared with the Duncan test. In this case, homogeneity groups were determined depending on the lowest significant difference (LSD) critical value in the ranking of the factors affecting the results.

3 Results and Discussion

The statistical data of the air dry density value of the test samples of wood, LVL, and RLVL manufactured from heat-treated scotch pine veneer are given in detail in Table 1. Average air-dry density values of the wood test specimens vary between 0.441-0.467 g/cm^3, 0.456-0.482 g/cm^3 for LVL samples and 0.471-0.494 g/cm^3 for reinforced LVL samples. According to Table 1, the highest density value was found in the unheated and reinforced test specimens as 0.494 g/cm^3 and the lowest in the wood specimens heat-treated at 200 °C as 0.441 g/cm^3.

Table 1. Statistical results for air dry density values

Experimental Group	Heat treatment	Mean (g/cm^3)	HG	Min (g/cm^3)	Max (g/cm^3)	SD
Wood	Unheated	0.467	I	0.448	0.479	0.01066
	140 °C	0.461	K	0.441	0.475	0.01155
	160 °C	0.456	L	0.441	0.471	0.01053
	180 °C	0.449	M	0.435	0.465	0.01156
	200 °C	0.441	N	0.423	0.462	0.01265
LVL	Unheated	0.482	D	0.466	0.508	0.01342
	140 °C	0.475	F	0.457	0.495	0.01131
	160 °C	0.469	H	0.447	0.488	0.01172
	180 °C	0.463	J	0.441	0.479	0.01347
	200 °C	0.456	L	0.429	0.473	0.01238
RLVL	Unheated	0.494	A	0.477	0.512	0.01292
	140 °C	0.491	B	0.476	0.517	0.01405
	160 °C	0.484	C	0.473	0.501	0.01586
	180 °C	0.477	E	0.462	0.496	0.01058
	200 °C	0.471	G	0.449	0.483	0.01135
LSD		±0.0008845				

Mean: Average value, Min: Minumum value; Max: Maximum value, SD: Standard deviation; HG: Homogeneity groups

Variance analysis (ANOVA) regarding the effects of reinforcement and heat treatment temperatures on air dry density, equilibrium moisture content, and compressive strength parallel to the grain of the produced test samples usage heat-treated scotch pine (*Pinus sylvestris* L.) veneers are given in Table 2. Accordingto the test results, the effects of heat treatment condition and reinforcement process on density properties of wood, LVL and RLVL specimens were statistically significant ($p \leq 0.05$). However, dual interactions of these factors on the density values were not found to be significant.

Density is an important physical property of the usability of wood and it significantly affects mechanical properties of wood and wood-based composites. Density decreased with increasing heat treatment temperature in all test groups according to Table 1. On the other hand, the density values of LVL and RLVL are higher than those of heat-treated solid wood under the same conditions. The increase in density in LVL compared to wood may be due to the adhesive applied between the veneers. The density of LVL has increased due to the adhesive and pressure applied in the production of laminated wood materials. However, the density values of RLVL are higher than both wood and LVL samples. This increase may be due to more adhesive being applied between the wood veneers, press pressure and glass fiber fabric used in the reinforcement process. Bal (2014a) reported significant increases in the density values of laminated veneer lumber reinforced with glass fiber in his study. In another study, Bal (2014b) reinforced the veneers obtained from poplar wood with glass fiber and reported that the density values of the obtained composite materials increased.

According to Table 1, the results showed that the density of wood samples decreased after heat treatment. Heat-treated wood samples at a temperature of 200 °C gave the lowest air-dry density value when compared with other heat-treated specimens. The weight of wood material after heat treatment decreased with an increase in temperature. These changes after heat treatment of wood material at high temperatures may be due to loss of material in the cell walls, degradation of extractive substances, and degradation of hemicellulose (Korkut et al., 2008a)

Table 2. ANOVA results for tested properties of heat-treated and reinforced wood specimens

Test	Source	Degress of Freedom	Sumof Squares	Mean Squares	F value	Sig.
Density	Reinforcement (A)	2	0.020	0.010	71.1877	0.0000
	Heat treatment (B)	4	0.012	0.003	20.5668	0.0000
	AxB	8	0.000	0.000	0.0557	
	Error	135	0.019	0.000		
	Total	149	0.052			
Equilibrium moisture content (EMC)	Reinforcement (A)	2	11.198	5.599	14.3573	0.0000
	Heat treatment (B)	4	339.884	84.971	217.8896	0.0000
	AxB	8	4.675	0.584	1.4986	0.1633
	Error	135	52.646	0.390		
	Total	149	408.404			
Compressive strength parallel to the grain	Reinforcement (A)	2	472.144	236.072	20.7395	0.0000
	Heat treatment (B)	4	593.629	148.407	13.0380	0.0000
	AxB	8	4.863	0.608	0.0534	
	Error	135	1536.664	11.383		
	Total	149	2607.299			

Reinforcement: Wood, LVL, RLVL; Heat treatment: 140 °C, 160 °C, 180 °C, and 200 °C.

The determined EMC values of the experimental groups are given in Table 3. According to these results, EMC values in all heat-treated experimental groups decreased with increasing heat treatment temperature. The highest EMC value was found in specimens without heat treatment, while the lowest was found in specimens heat-treated at 200 °C in all experimental groups. In addition, heat treatment showed a similar effect in wood, LVL and RLVL composites.

The equilibrium moisture content of heat-treated wood material at high temperatures decreases, and the wood becomes less hydrophilic. An important reason for this change is the decrease in the hydroxyl groups in hemicellulose and cellulose, which are hydrophilic components of wood. Lignin branching also contributes to this change (Korkut and Kocaefe 2009; Esteves and Pereira 2009). In the literature, it is stated that the heat treatment of wood results in a reduction in accessible hydroxyl content (Hill et al., 2021). Also, the hygroscopicity of the heat-treated wood material decreases significantly and the dimensional stability of the wood material increases. In addition, especially at high temperatures, the hydroxyl groups in the wood material break down and the wood cannot take in as much water as before. Therefore, the sorption capacity of wood may decrease significantly (Aydemir and Gündüz, 2009). Especially at high temperatures, heat treatment can effectively reduce the hygroscopicity of wood because it significantly thermally degrades hemicellulose (Li et al. 2017). In another study, it was stated that the dimensional stability of the wood material improved with the decrease in hygroscopicity after heat treatment, and esterification of hydroxyl groups and crosslinking reactions were effective in the decrease of hygroscopicity (Tjeerdsma and Militz, 2005). Heat treatment reduces the equilibrium moisture content of the wood material, and the EMC value is significantly lower than in untreated wood at high temperature. Since the hydroxyl groups of heat-treated wood are decreased, cell wall hygroscopicity is reduced, and therefore, the expansion of the wood is reduced (Mayes and Oksanen, 2002). Sivrikaya et al., (2022) reported that the EMC value of Scotch pine (*Pinus sylvestris* L) samples decreased significantly after the vacuum-heat treatment process.

According to Table 2, the effect of heat treatment condition and reinforcement process on EMC values of wood, LVL and RLVL specimens was statistically significant ($p \leq 0,05$). However, the dual interaction of these factors on the EMC value was not found to be significant.

Table 3. Statistical results for EMC values of test specimens

Wood type	Heat treatment	Mean (%)	HG	Min (%)	Max (%)	SD
Wood	Unheated	13.36	A	12.11	14.32	0.69638
	140 °C	12.77	ABC	11.72	13.71	0.70845
	160 °C	12.13	EFG	11.05	13.48	0.88179
	180 °C	11.72	G	11.55	12.45	0.54589
	200 °C	8.91	JK	8.11	10.11	0.58608
LVL	Unheated	13.15	AB	12.32	14.65	0.76724
	140 °C	12.59	CDE	11.85	13.48	0.58031
	160 °C	11.98	FG	10.48	12.75	0.78061
	180 °C	11.10	H	10.62	12.17	0.44158
	200 °C	9.12	J	8.11	9.69	0.57814
RLVL	Unheated	13.01	ABC	12.12	14.13	0.56766
	140 °C	12.34	DEF	11.61	13.11	0.55542
	160 °C	11.66	G	10.75	12.65	0.64684
	180 °C	10.21	I	9.75	11.33	0.45753
	200 °C	8.55	K	7.85	9.11	0.41363
LSD	±0.5523					

According to Table 3, the highest EMC value was found in unheated wood specimens as 13.36 %, and lowest in heat-treated at 200 ºC and reinforced specimens as 8.55%. EMC values exhibited similar behavior in all experimental groups. The lowest EMC was determined in specimens heat-treated at 200 °C compared to the experimental groups without heat treatment. On the other hand, the EMC values of all heat-treated and reinforced experimental groups are lower than those of solid wood and LVL samples treated under the same conditions. Furthermore, the EMC values of all LVL samples are lower than those of solid samples except for the 200 ºC heat-treated samples. This may be because the adhesive applied between the wood veneers and the glass fiber used for reinforcement process prevents the transport of moisture. This may be due to the hydrophobic properties of the adhesive used in the bonding process. Bal and Bektaş (2012) analyzed that the EMC of LVL composite materials manufactured from *Eucalyptus grandis*, *Populus x euramericana*, and *Fagus orientalis* woods using some adhesives. They reported that the EMC values of LVL were lower than solid wood. LVL composites may have lower EMC values than solid wood due to press temperature, drying and adhesive properties (Shukla and Kandem, 2008).

Compression strength parallel to the grain value and statistics properties for materials are given in Table 4. The results of the variance analysis performed to determine the effect of heat treatment and reinforcement process on the compressive strength parallel to the grain values are given in Table 2. According to these results, the effect of thermal treatment conditions and reinforcing process on compressive strength parallel to the grain properties of wood, LVL and RLVL specimens was statistically significant ($p \leq 0,05$). However, dual interactions of these factors on the compressive strength parallel to the grain values were not found to be significant.

A general increase in the compressive strength parallel to the grain was determined as the applied heat treatment temperature increased according to the findings in Table 4. The comparison results of the average the compressive strength parallel to the grain values using the LSD: 1.721 N/mm² critical value for heat treatment and LSD: 1.333 for reinforcement process are given in Table 5. Accordingly, heat treatment temperature and reinforcement processes gave statistically significant values on the compressive strength values parallel to the grain.

According to Table 5, the compressive strength parallel to the grain increased for all samples except those heat-treated at 200 °C when compared to the unheated specimens. In general, heat treatment at lower temperatures led to an increase in compressive strength parallel to the grain (Figure 4). However, the compressive strength tended to decrease at higher temperatures, particularly at 200 °C. According to Figure 4, when interactions of the heat treatment and reinforcement process, the highest compressive strength (51.21 N/mm²) was observed in samples heat-treated at 180 °C, while the lowest (45.81 N/mm²) was found in samples heat-treated at 200 °C.

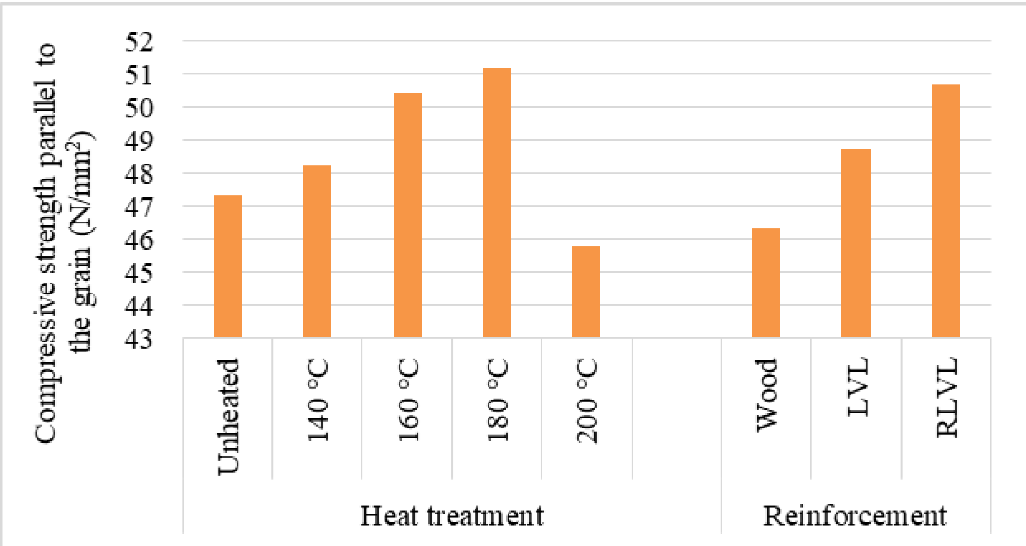

Figure 4. Compressive strength parallel to the grain according to heat treatment and reinforcement process

The increases in compressive strength parallel to the grain are due to the decrease in the relative water content as a result of heat treatment. Due to the degradation or crystallization of amorphous cellulose after heat treatment, the amount of highly ordered crystalline cellulose increases. Because crystalline cellulose exhibits an anisotropic structure, its solid and rigid structure causes an increase in compressive strength parallel to the grain (Korkut and Kocaefe, 2009). It is reported in a similar study conducted by Boonstra et al. (2007), that the increase of the compressive strength in longitudinal direction might be due to a lower amount of bound water in heat-treated wood. Also, it is reported that the amount of the highly ordered crystalline cellulose increases due to degradation and crystallization of amorphous cellulose during heat treatment. Since crystalline cellulose shows significant anisotropy, its stiff and rigid structure might be responsible for the observed increase of the compressive strength in the longitudinal direction. An increased cross-linking of the lignin polymer network could be another reason for this improvement (Boonstra et al., 2007). The findings obtained from this study are generally consistent with the literature. In a similar study, Yapıcı et al., (2010) determined the compressive strength of bonded Scotch pine (*Pinus sylvestris* L.) wood samples with D-VTKA adhesive after heat treatment at 110, 130, 150 and 170°C. As a result, they reported that the compressive strength of the bonded samples increased after heat treatment while the heat treatment applied at high temperatures decreased the compressive strength. Boonstra et al., (2007) analyzed the changes in compressive strength values parallel to the grain after heat treatment of different wood materials, including Scots pine (*Pinus sylvestris* L). As a result, it was reported that the compressive strength values parallel to the grain of heat-treated wood materials were 28% higher than the non-heat-treated group. On the other hand, Korkut et al., (2008b) applied heat treatment to Scots pine (*Pinus sylvestris* L) test samples at varyings temperatures (120 °C, 150 °C and 180 °C) and durations (2, 6 and 10 hours), and analyzed the effect of heat treatment on some physical and mechanical properties. As a result, it was reported that the compressive strength values parallel to the grains decreased in all heat-treated experimental groups compared to the control specimens.

The average compressive strength values of LVLs are higher than those of wood treated under the same conditions. This may be due to the higher density values of LVL samples compared to wood. Press conditions and the adhesive applied to the veneers increased the density values of LVL samples. This may have caused LVL samples to give higher compressive strength values compared to solid wood. Density is one of the important physical properties of wood and is closely related to other mechanical properties, such as compressive strength values parallel to the grain (Arriaga et al., 2023). Keskin et al., (2003) analyzed some physical and mechanical properties including compressive strength parallel to the grain of laminated veneer lumber obtained from scotch pine (*Pinus sylvestris* L.) wood using PVAc-D4 adhesive. As a result, they reported that the compressive strength values of LVL test specimens were 4.52 % higher than solid wood.

According to Table 5, the average compressive strength parallel to the grain of the reinforced LVL (50.70 N/mm^2) is higher than that of wood (46.36 N/mm^2) and LVL (48.75 N/mm^2) by 9% and 4%, respectively. Also, the compressive strength of LVL samples was 5% higher than wood. According to these results, there was a general increase in the compressive strength parallel to the grain in all heat-treated and reinforced experimental groups, which was caused by the increase in density values due to the combination of adhesive and reinforcement. It is thought that the increase in density, the adhesive used, and reinforcing materials applied between the wood veneers are effective in the emergence of these results. In the literature, Basterra et al., (2012) obtained double beams from poplar (Populus xeuramericana cv. I-214) wood samples reinforced with glass fiber, carbon fiber and flax fiber materials. As a result of the mechanical tests using the reinforced materials in the experimental results, there were significant increases in the strengthening studies with carbon fiber, while no statistically significant increase was determined in the strengthening studies with glass fiber and flax fiber. Fiorelli and Dias (2006) bonded glulam samples prepared from *Pinus caribaea var. hondurensis* wood reinforced with different thicknesses glass fiber fabrics with Phenol-resorcinol (AxoNobel) adhesive and analyzed some mechanical properties. As a result, it was reported that the mechanical properties of glass fiber reinforced glulam composite materials increased. In a similar study, Bal and Özyurt (2015) analyzed the changes in some physical and mechanical properties of poplar composite materials reinforced with glass fiber fabrics. As a result, it was reported that glass fiber significantly increased the density, modulus of elasticity and shock resistance while decreasing the tensile-compression resistance, thickness swelling and water absorption percentages. In another study, Çiğdem and Perçin (2023) reinforced veneers obtained from beech wood with carbon fiber and glass fiber fabrics using phenol formaldehyde (FF) adhesive after heat treatment at 150, 175 and 200°C for 3 hours. According to the results, increases in the compressive strength values parallel to the grain of the heat-treated composite materials reinforced with carbon fiber and glass fiber fabrics were determined. Similarly, Perçin (2023) heat-treated black pine (*Pinus nigra*) wood materials were reinforced using carbon fiber fabric after heat treatment at 150, 175 and 200 °C for 2 hours. As a result, the compressive strength parallel to the grain of the reinforced test specimens was higher than that of the control group. In another study Karaman (2025) reinforced beech samples with basalt fiber reinforced polymer (BFRP), glass fiber reinforced polymer and plaster mesh (PSM) using different wooden dowel species. He reported the significant effects of reinforcement on tensile strength perpendicular to the grains.

Table 4. Compressive strength parallel to the grain of the experimental group

Wood type	Heat treatment	Mean (N/mm^2)	HG	Min (N/mm^2)	Max (N/mm^2)	SD
Wood	Unheated	45.13	GH	41.14	50.92	3.18
	140 °C	46.17	FGH	41.48	52.14	3.33
	160 °C	48.14	DEF	43.29	53.24	3.12
	180 °C	48.97	CDEF	44.34	53.45	2.85
	200 °C	43.39	H	40.44	47.49	2.75
LVL	Unheated	47.12	EFG	42.34	53.11	3.35
	140 °C	48.23	DEF	43.69	53.23	2.91
	160 °C	50.62	ABCD	46.57	55.39	3.01
	180 °C	51.53	ABC	46.59	56.11	2.97
	200 °C	46.27	FGH	42.49	51.67	2.91
RLVL	Unheated	49.71	BCDE	45.36	56.52	3.20
	140 °C	50.27	ABCD	45.89	56.17	3.42
	160 °C	52.61	AB	47.12	59.12	3.63
	180 °C	53.12	A	47.49	60.39	4.52
	200 °C	47.78	DEFG	41.44	56.17	4.77
LSD	±2.981					

Table 5. Comparison of average compressive strength parallel to the grain according to heat treatment and reinforcement

	Heat treatment	
	Mean (N/mm^2)	HG
Unheated	47.32	BC
140 °C	48.22	B
160 °C	50.46	A
180 °C	51.21	A
200 °C	45.81	C
LSD	±1.721	
	Reinforcement	
Wood	46.36	C
LVL	48.75	B
RLVL	50.70	A
LSD	±1.333	

4 Conclusion

In this study, air dry density, EMC, and compressive strength parallel to the grain were analyzed for solid wood, LVL, and RLVL samples obtained from heat-treated scotch pine (*Pinus sylvestris* L) at 140 °C,160 °C,180 °C and 200 °C for 3 h. According to the results obtained from the study;

- Density, EMC and compressive strength parallel to the grain were affected by heat treatment, lamination and reinforcement processes.
- Density values decreased with increasing heat treatment temperature in all experimental groups. The highest density was obtained for reinforced and unheated samples as 0.494 g/cm^3. The lowest density was optained for heat-treaed samples at 200 °C as 0.441 g/cm^3. Air-dry density values of LVL samples were higher than wood, while RLVL samples were higher than both LVL and wood samples.
- Applied heat treatment, lamination process and glass fiber reinforcement reduced the EMC values of the test samples. The highest EMC was recorded in unheated wood as 13.36%, and the lowest in reinforced and heat-treated samples at 200 °C as 8.55%.
- The compressive strength parallel to the grain of the heat-treated and then glass fiber reinforced scotch pine samples was improved. The highest CS value was found to be 53.12 N/mm^2 in samples strengthened and heat treated at 180 °C, and the lowest CS value was found to be 43.39 N/mm^2 in wood heat treated at 200 °C. In addition, only the lamination process caused slight increases in compressive strength compared to wood samples.
- In future studies, it may be recommended to investigate the changes in physical and mechanical properties of heat-treated wood materials at different temperatures by reinforcing them with reinforcement materials, such as Aramid FRP (AFRP), Carbon Fiber Reinforced Polymer (FRP), Kevlar fiber, and also natural fibers such as linen, hemp, jute and bamboo, ramie, etc.

Author Contribution

Osman Perçin: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest
The author declares no conflict of interest.

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Improving durability and mechanical resistance of wood/plastic composites through boric acid treatment

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ABSTRACT: In this study, the effects of boric acid (BA) treatment on the mechanical properties and decay resistance of poplar wood flour/polypropylene composites (WPCs) were investigated. Three composite groups were prepared: untreated WPC (UT-WPC), BA-treated WPC with in-process powder addition (BA-T-WPC), and BA-pretreated WPC using aqueous BA solution (BA-PT-WPC). Mechanical properties including flexural strength and modulus, tensile strength and modulus, hardness, and impact strength were evaluated before and after exposure to fungal decay (*Trametes versicolor*). The results showed that boric acid treatment improved several mechanical properties of undecayed WPC. Specifically, BA-T-WPC exhibited the highest flexural strength (50.77 MPa) and modulus (3473 MPa), while BA-PT-WPC demonstrated superior tensile modulus (4563 MPa) and impact strength (49.40 J/m). Decay exposure decreased all mechanical properties across all groups, although BA-treated samples retained slightly higher performance compared to the untreated control. These findings suggest that boric acid can effectively enhance the mechanical behavior and decay resistance of WPCs through both direct and pretreatment methods.

Keywords: WPC, poplar wood, boric acid, durability, physical and mechanical resistance

Ahşap/plastik kompozitlerin dayanıklılığı ve mekanik direncinin borik asit uygulamasıyla artırılması

ÖZ: Bu çalışmada, borik asit (BA) işleminin kavak odun unu/polipropilen kompozitlerinin (WPC'ler) mekanik özellikleri ve çürümeye karşı direnci üzerindeki etkileri araştırılmıştır. Üç kompozit grubu hazırlanmıştır: işlenmemiş WPC (UT-WPC), işlem sırasında toz halinde BA ilave edilerek hazırlanmış WPC (BA-T-WPC) ve sulu BA çözeltisiyle ön işlem uygulanmış WPC (BA-PT-WPC). Eğilme direnci, eğilme modülü, çekme direnci,çekme modülü, sertlik, ve darbe direnci gibi mekanik özellikler Trametes versicolor mantarıyla çürütme öncesi ve sonrası değerlendirilmiştir. Sonuçlar, borik asit işleminin çürümemiş WPC'nin bazı mekanik özelliklerini geliştirdiğini göstermiştir. Özellikle, BA-T-WPC en yüksek eğilme direnci (50.77 MPa) ve modülünü (3473 MPa) sergilerken, BA-PT-WPC en yüksek çekme modülü (4563 MPa) ve darbe dayanımı (49.40 J/m) göstermiştir. Çürümeye maruz kalma tüm gruplarda mekanik özellikleri azaltmış olsa da, BA ile muamele edilmiş örnekler, işlem görmemiş kontrol grubuna kıyasla biraz daha yüksek performans göstermiştir. Bu bulgular, borik asidin hem doğrudan hem de ön işlem yoluyla WPC'lerin mekanik davranışını ve çürümeye karşı direncini etkili bir şekilde artırabileceğini göstermektedir.

Anahtar kelimeler: WPC, kavak ağacı, borik asit, dayanıklılık, fiziksel ve mekanik direnç

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1 Introduction

Wood plastic composites (WPCs) are important and promising engineered wood products that are widely used in areas like landscaping, transportation, municipal engineering, and construction. Wood plastic composites (WPCs) have advanced significantly within the thermoplastic industry, being utilized in a variety of applications such as interior automotive panels, garbage containers, crates, and garden tools (Hornsby et al., 1997). They have also seen substantial development in exterior nonstructural or semi-structural building products, including door and window frames, siding, decking, cladding, floor and roof tiles, and fencing (Schneider et al., 2000).

They incorporate natural fibers, including wood flour, pulp fibers, and cellulose fibers, to reinforce thermoplastics such as polyethylene (both high and low density), polypropylene, and PVC. The appeal of using these natural fibers lies in several advantages, including reduced production costs and density, simplified preparation processes, lower energy consumption during processing, biodegradability, and broader applicability compared to traditional reinforcing fibers like glass and carbon (Chaharmahali et al., 2010).

WPCs are recognized for their excellent durability, dimensional stability, high rigidity, and relatively low density (Schneider et al., 2000; Ashori, 2008). However, their broader adoption is significantly limited due to their inadequate fire resistance (Mouritz and Gibson, 2006; Chapple and Anandjiwala, 2010).

In light of the global crisis regarding the scarcity of forestry and fossil oil resources, projections suggest that the use of natural fiber-reinforced composites is expected to increase from 12% in 2010 to 18% by 2020, and further to 25% by 2030 (Gurunathan et al., 2015). As the demand for engineered wood products rapidly increases across various applications, wood plastic composites (WPCs) have emerged as a leading type of natural fiber-reinforced composite. WPCs are primarily made from thermoplastic polymers such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS), combined with biomass particles and fibers sourced from forestry and agricultural waste, including wood, bamboo, straw, stalks, husks, and bast. These materials are regarded as essential and innovative options for both residential and industrial construction (Adhikary, 2011).

Borates offer several benefits as wood preservatives. They not only provide flame retardation but also protect against organisms that damage wood, possess low toxicity to mammals, and have low volatility. Additionally, borates are both colorless and odorless and non-corrosive, have been utilized for many years as low-toxicity wood preservatives mainly to enhance biological resistance and thermal stability in wood (Murphy, 1990; Drysdale, 1994; Chen et al., 1997; Yalinkilic et al., 1997). However, they tend to leach from treated wood that is in contact with the ground during rainfall (Yalinkilic et al., 1997). As a result, boron compounds are primarily used in indoor settings. The future use of boron preservatives relies on enhancing their stability in wood for effective protection over a significant duration (Nicholas et al., 1990) and improving the negative characteristics of boron-treated wood through additional treatments (Yalinkilic et al., 1997). Consequently, the combination of borates with other preservatives has been thoroughly studied for outdoor wood preservation (Devi and Maji, 2007; Murphy et al., 1995).

Fruno et al., (1993) explored the use of boron compounds, including boric acid, borax, boron trioxide, ammonium borate, and potassium borate, to create insoluble organic substances in wood through a reaction with water glass acid treatment. They discovered that utilizing the water glass-boron compound system enabled the formation of a composite material that offered improved dimensional stability, reduced hygroscopicity, and enhanced fire resistance. Bal et al., (2023) found that increasing wood flour in composite boards made from waste plastic furniture parts decreased flexural and tensile strengths and elongation, while increasing density, hardness, and stiffness. TGA and DSC analyses showed the plastics mainly consisted of LLDPE and PP, with decomposition temperatures rising as wood flour content increased.

Thermal treatment of wood flour affects the physico-mechanical properties of wood plastic composites, with some improvements in strength and reduced water uptake at specific temperatures and durations. Fungal decay generally decreased mechanical properties, but treated samples showed better resistance in moisture-related parameters compared to decayed ones (Hosseinihashemi and Arwinfar, 2023). Baysal et al., (2007) examined the physical, biological, mechanical, and fire properties of wood polymer composites (WPC) made from vinyl monomers such as styrene (ST), methylmethacrylate (MMA), and a 50:50 mixture of the two, using treated sapwood from Scots pine (*Pinus sylvestris* L.). They first impregnated the wood with a 1% concentration of a boric acid (BA) and borax (BX) mixture before applying the monomer treatment. Their findings indicated that the vinyl monomers significantly improved the physical properties of the wood, resulting in increased anti-swelling efficiency (ASE), specific gravity (SG), and decreased water absorption (WA). Furthermore, the modulus of elasticity (MOE) and modulus of rupture (MOR) for the treated samples surpassed those of untreated control specimens. Although the ASE, MOE, and MOR for the WPC pre-impregnated with the BA and BX mixture were somewhat diminished, its fire resistance was enhanced. Bal (2022) investigated the production of wood plastic composites (WPCs) using a flat pressing method without an extruder, utilizing linear low-density polyethylene and pine wood flour with varying filler rates (0%, 10%, 20%, 30%, and 40%). Results indicate that increasing wood flour content enhances density, bending strength, and stiffness, while reducing elongation at break, highlighting the effects of filler percentage on WPC performance.

The aim of this study was to investigate the effect of boric acid (BA) treatment on the decay, water, and mechanical resistance performances of impregnated beech wood flour (WF) filled polypropylene composites.

2 Material and Method

2.1 Polymer matrix, reinforcing filler, coupling agent, and preservative

Poplar wood flour (PWF) was used as the lignocellulosic filler and sourced from the Amol farms of Iran. The thermoplastic matrix was polypropylene (PP) with a melt flow index of 10 g/10 min, supplied by the Tabriz Petrochemical Company of Iran. The maleic anhydride polypropylene (MAPP) from Eastman Chemical Products, Inc., as Epolene G-3003™ polymer with 8% acid anhydride and a molecular weight of 103.500 was used as a compatibilizer to improve adhesion between the hydrophilic wood flour and the hydrophobic PP matrix. Boric acid (H_3BO_3, ≥99% purity) was obtained from laboratory of Department of Wood Science and Paper Technology, Ka.C., Islamic Azad University.

2.2 Composite formulation

The formulations of the composite materials are presented in Table 1. Three groups were prepared:

UT-WPC: Untreated poplar wood flour/polypropylene composite, containing 40 wt% PWF, 58 wt% PP, and 2 wt% MAPP.

BA-T-WPC: Composite with boric acid added as powder (1 wt%) during the mixing process (treated in-process).

BA-PT-WPC: Composite containing boric acid-pretreated wood flour soaked in a 1 wt% aqueous solution of boric acid and oven-dried prior to compounding.

Table 1. Formulation of composites

WPC Code	BA Concentration (wt %)	Wood flour (wt %)	Polypropylene (wt %)	MAPP (wt %)
UT-WPC	0	40	58	*2*
BA-T-WPC	1 in powder	39	58	2
BA-PT-WPC	1 in solution	40	58	2

UT-WPC: untreated poplar wood flour/plastic composite; BA-T-WPC: boric acid treated poplar wood flour in manufacturing process/plastic composite; BA-PT-WPC: boric acid pretreated poplar wood flour/plastic composite; MAPP: maleic anhydride polypropylene.

2.3 Pretreatment and processing

For BA-PT-WPC, the poplar wood flour was immersed in a 1 wt% boric acid solution for 24 hours at room temperature. The soaked flour was then dried in an oven at 103 ± 2 °C until constant weight was achieved.

For BA-T-WPC, boric acid powder (1 wt%) was directly added to the blend during compounding without prior treatment of the wood flour.

All formulations were mixed using a twin-screw extruder operating at 160-180 °C with a screw speed of 60 rpm. The compounded materials were then pelletized and molded into standard test specimens by compression molding at 180 °C under 5 MPa pressure for 10 minutes, followed by cooling under pressure.

2.4 Decay resistance test

To evaluate biological durability, half of the test specimens were exposed to decay using the agar-block test method (ASTM D1413), with *Trametes versicolor* (white-rot fungus) as the degrading agent. Samples were incubated for 14 weeks at 23 ± 2 °C and 75% relative humidity (Figure 1).

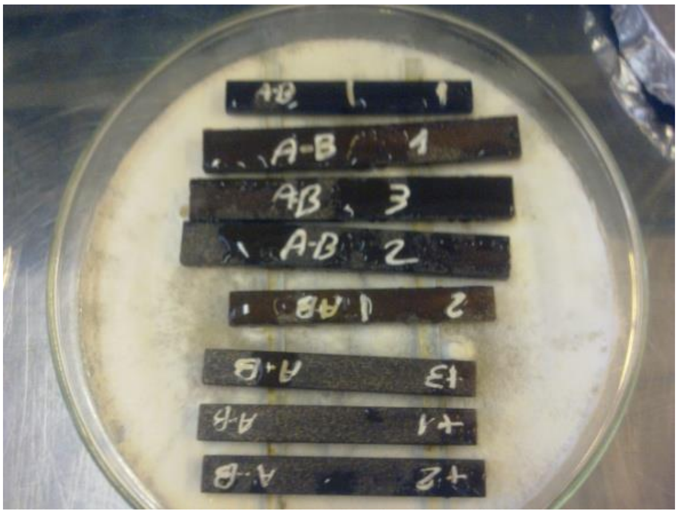

Figure 1. A typically of several BA-T-WPC and BA-PT-WPC samples exposed to white-rot fungus using the agar-block test method

2.5 Mechanical testing

Mechanical properties of both decayed and undecayed samples were measured as follows: Flexural strength and modulus – ASTM D790; Tensile strength and modulus – ASTM D638; Hardness – ASTM D2240 (Shore D); Impact strength – ASTM D256 (Izod method).

All tests were conducted on four replicates (N = 4) for each group. Statistical analysis was performed using SPSS software version (17 version]), and results are presented as mean ± standard deviation.

2.6 Water uptake and dimensional stability tests

Water uptake and thickness swelling tests of the composites were conducted by following the ASTM D 570 (1998) standard. Five specimens from each formulation were selected and oven-dried for 24 h at 100 ± 3 °C. The samples were weighted with an accuracy of 0.001 g after drying in the oven and their thicknesses were measured at an accuracy of 0.001 mm. Then, the specimens were placed in distilled water for 24 h by the method of immersion and retained at room temperature (20 ± 2 ºC). In the final of this time, the excess on the surface of the specimen was cleared with a clean cloth and then their weights and thicknesses were determined.

2.7 Fungus culture

The white-rot fungus (*T. versicolor*) was transferred to petri dishes containing malt extract agar (48 g/L) under laminar hood using sterile pincers. The plates were kept at 23 ºC for one week until the culture medium was fully covered by the mycelium of the fungus. The cultured fungus was transferred into petri dishes containing the culture medium and then incubated for one week at 23 ºC.

2.8 Inoculation of samples by fungus

Inoculation of composite samples by the fungus was performed in the petri dishes. The dishes containing the fungus and the composite samples were incubated in an incubator for 14 weeks at 23 ºC and 75% RH. The sizes of control WPCs samples are shown in the Figure 2.

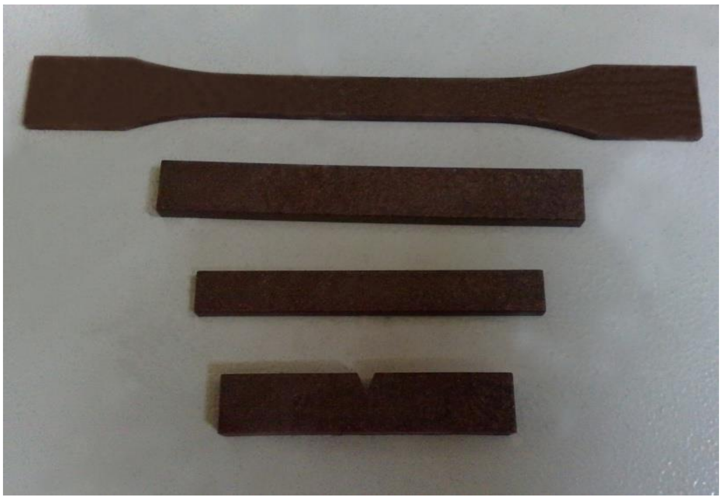

Figure 2. The sizes of WPCs control samples

2.9 Data analysis

Mass loss, flexural strength, flexural modulus, tensile strength, tensile modulus, impact strength, water absorption, and thickness swelling values were evaluated using a computerized SPSS 17.0 statistical program and tested with ANOVA followed by Duncan's Multiple Range Test (DMRT) with 95% confidence level.

3 Results and discussion

3.1 Weight loss

Figure 3 illustrates the weight loss of different wood-plastic composite (WPC) samples after exposure to the white-rot fungus *Trametes versicolor*. According to the data, the UT-WPC sample exhibited the highest weight loss, approximately 0.68%, indicating its low resistance to fungal decay. The BA-T-WPC sample, which was treated with boric acid during the mixing stage, showed a moderate reduction in weight loss about 0.35% demonstrating improved fungal resistance. The BA-PT-WPC sample, where wood flour was pretreated with a boric acid solution before composite processing, had the lowest weight loss at approximately 0.25%. These results reveal that boric acid treatment enhances the durability of WPCs against fungal attack. Specifically, pre-treatment of the wood flour (BA-PT-WPC) reduced weight loss by nearly 63% compared to the untreated control, and by 48% compared to in-process treatment (BA-T-WPC). According to the results of the Duncan test, no statistically significant differences were found between the groups. Although the graph suggests that the application of boric acid and its usage through different methods may have some slight effect. This strategy could be highly beneficial for extending the service life of wood-plastic composites in environments prone to fungal exposure.

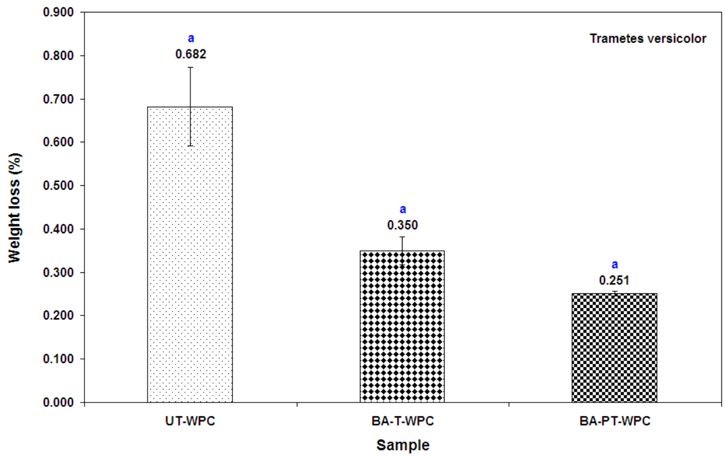

Figure 3. Effect of boric acid treatment on weight loss of wood flour/polypropylene composites (Duncan's multiple range tests are given in the graph)

The results of an investigation by Cavdar et al., (2018) on the effect of boron compounds (spruce wood flour was treated with boric acid (BA), borax (BX), and a BA-BX mixture, then incorporated into a polymer matrix at 20% and 40% loading rates) on the decay resistance and weight loss (brown-rot fungus, *Coniophora puteana* and white-rot fungus, *Trametes versicolor*) of wood-plastic composites (WPCs) indicated that boron-treated composites exhibited higher weight loss and moisture content compared to controls during decay tests. Notably, composites with higher wood flour content showed increased susceptibility to fungal decay, emphasizing the need for optimized treatment methods to enhance durability.

3.2 Hardness

The hardness of both UT-WPC and BA-PT-WPC samples decreased after exposure to fungal attack, except for the BA-T-WPC specimens. The results of Duncan's test indicated that the BA treatment had significant effect on the hardness of wood flour/polypropylene composites. In addition, there were significant differences between hardness values of BA-PT-WPC and BA-T-WPC undecayed samples (P<0.05). As can be seen in Figure 4, in comparison to UT-WPC (70.25 Shore D) the minor decrease (70.16 Shore D) and slight increase (71.22 Shore D) found in the hardness values of BA-T and BA-pretreated undecayed samples may be due to the precipitation of BA in the cell lumens and the cell wall of wood particles and the subsequent increase in density. It appears that in the BA-T-WPC samples, boric acid have precipitated on the surface and did not penetrate into the cell lumen or cell wall, but in the BA-PT-WPC, boric acid have precipitated in the cell cavity and the cell wall (Winandy and Rowell, 1984; Hosseini Hashemi et al., 2010; Badritala et al., 2013). After exposure to decay fungus, there were no significant differences between hardness values of BA-PT-WPC and BA-T-WPC decayed samples (P<0.05). Ünal et al., (2023) incorporated boric acid into polypropylene (PP) and wood flour composites and showed that while boric acid significantly enhanced, it caused a slight reduction in tensile strength. This decrease was attributed to the interference of boric acid with the bonding between the wood particles and polymer matrix, which negatively impacted interfacial adhesion.

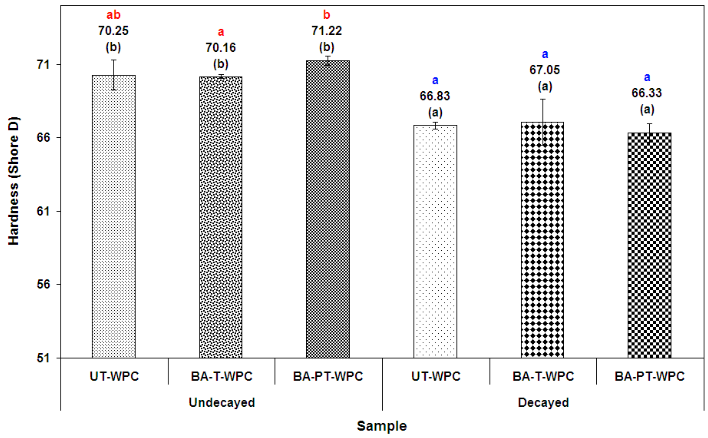

Figure 4. Effect of boric acid treatment on hardness of wood flour/polypropylene composites (Duncan's multiple range tests are given in the parentheses)

3.3 Impact strength

The results of Duncan's test indicated that the BA treatment had no significant effect on the impact strength of the composites before and after exposure to fungal attack, except for the BA-PT-WPC specimens (Figure 5). There were significant differences between BA-PT-WPC and BA-T-WPC undecayed and decayed samples (P<0.05). As can be seen in Figure 5, the specimens containing the BA-T and BA-PT showed lower and higher notched impact strength compared with the untreated specimens, respectively. The impact resistance of the BA-T-WPC and BA-PT-WPC specimens decreased by 14.7% and increased 7.2%, respectively, compared to the UT-WPC specimens. This was mainly attributed to the poor and rich compatibility between the BA-T and BA-PT wood and polymer matrix due to the crystalline deposits of boric acid, respectively (Ayrilmis et al., 2012). Also, the BA-PT-WPC specimens exhibited marginally greater average impact resistance compared to the BA-T-WPC ones. We expected that the BA treatment is probably affected on dispersion and precipitation of BA particles in the cavities of composites. This result can be attributed to the formation of agglomeration cause to reduction of adhesion in the composite interface compared with the BA-PT specimens. After exposure to decay fungus, there were significant differences between impact strength values of BA-T-WPC and BA-PT-WPC decayed samples ($P<0.05$).

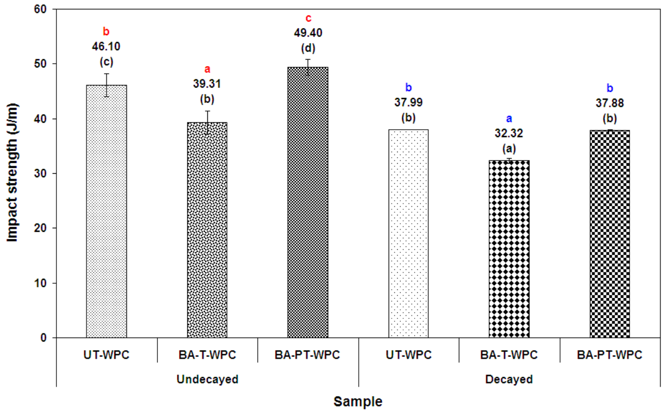

Figure 5. Effect of boric acid treatment on impact strength of wood flour/polypropylene composites (Duncan's multiple range tests are given in the parentheses)

Generally, it has been observed that boric acid, while beneficial for improving decay resistance, tends to reduce the impact strength of WPCs. This reduction is often attributed to the interference of boric acid with the interfacial bonding between the wood fibers and the polymer matrix, which weakens the load transfer during impact loading. For instance, Baysal et al., (2007) reported a moderate decrease in impact resistance when boric acid was incorporated, due to reduced compatibility between the components. Similarly, Ünal et al., (2023) investigated the mechanical properties of polypropylene (PP) composites filled with varying weight percentages (5%, 10%, and 15%) of boric acid (BA).They found that tensile strength and modulus decreased with increasing BA content.Impact strength increased slightly at 5% BA content but decreased at higher concentrations.These findings suggest that while low concentrations of boric acid can enhance certain mechanical properties, higher concentrations may have adverse effects.

3.4 Flexural strength and modulus

The results of Duncan's test indicated that the BA treatment had significant effect on the flexural strength of undecayed samples, but had no significant effect on the flexural strength of decayed samples. However, there was a significant differences between the flexural modulus values of the BA-T-WPC and BA-PT-WPC ($P<0.05$) in undecayed samples. As can be seen in Figures 6 and 7, the flexural strength and modulus of BA-PT-WPC and BA-T-WPC specimens were higher than the corresponding untreated specimens, except for the flexural modulus of BA-PT-WPC specimens. This is probably due to the increase in stiffness caused by formation of BA crystalline deposits in cell lumen of wood flour. This finding is consistent with those of previous studies (Ayrilmis et al., 2011; Ayrilmis et al., 2012; Kurt and Mengeloglu, 2011). Also, the BA-T-WPC specimens had higher flexural strength and modulus than the BA-PT-WPC ones. It seems that the specimens containing the BA-PT due to the formation of agglomeration cause to reduction of adhesion in the composite interface compared with the BA-T specimens. After exposure to decay fungus, there were no significant differences between flexural strength and modulus values of BA-T-WPC, BA-PT-WPC, and UT-WPC decayed samples ($P<0.05$).

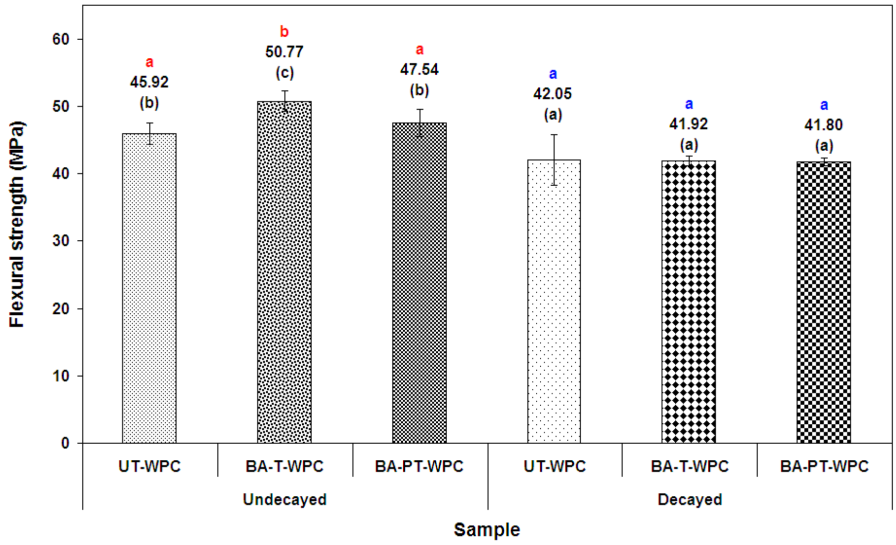

Figure 6. Effect of boric acid treatment on flexural strength of wood flour/polypropylene composites (Duncan's multiple range tests are given in the parentheses)

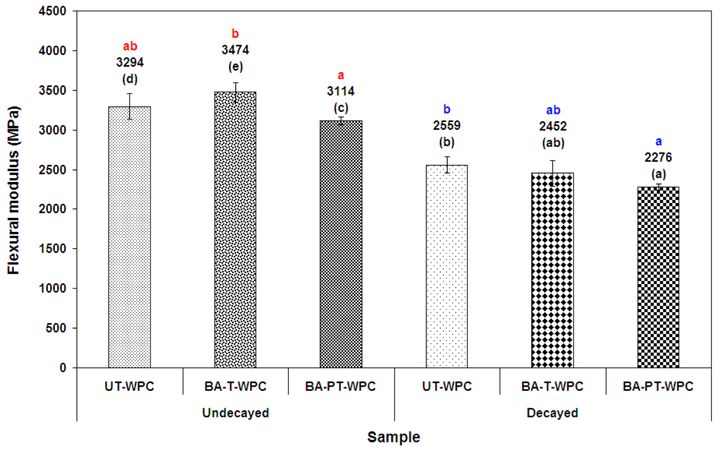

Figure 7. Effect of boric acid treatment on flexural modulus of wood flour/polypropylene composites (Duncan's multiple range tests are given in the parentheses)

The results of a study conducted by Baysal et al., (2007) on the effects of boric acid (BA) and borax (BX) pretreatment on the mechanical properties of wood-plastic composites indicated an increase in modulus of elasticity (MOE) and modulus of rupture (MOR) compared to untreated controls. Furthermore, the BA/BX treatment significantly enhanced the composites' resistance to fungal decay and improved their fire retardancy. These findings suggest that boron compounds can be beneficial in improving both the mechanical performance and durability of wood-plastic composites.

3.5 Tensile strength and modulus

The results of Duncan's test indicated that BA treatment had no significant effect on the tensile strength and modulus of the BA-treated WPC specimens ($P \geq 0.05$). Also, there were no significant differences between tensile strength and modulus values of UT-WPC, BA-T-WPC, and BA-PT-WPC. As can be seen in Figures 8 and 9, the tensile strength and modulus of BA-T-WPC and BA-PT-WPC specimens were higher than for the untreated specimens. Also, the

BA-T-WPC specimens had higher flexural strength than the BA-PT-WPC ones, but the BA-T-WPC specimens had lower flexural modulus than the BA-PT-WPC ones. The reduction of tensile strength and modulus in the BA-treated composites can be attributed to the same reasons as discussed concerning flexural strength and modulus.

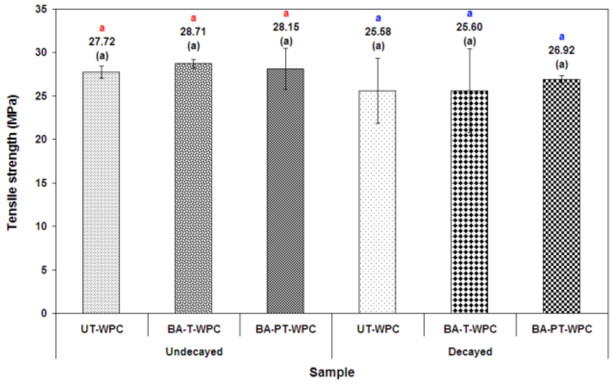

Figure 8. Effect of boric acid treatment on tensile strength of wood flour/polypropylene composites (Duncan's multiple range tests are given in the parentheses)

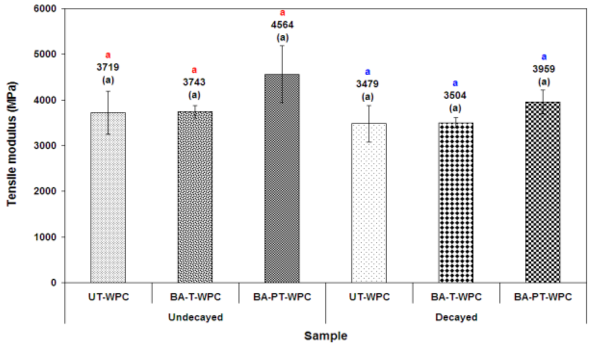

Figure 9. Effect of boric acid treatment on tensile modulus of wood flour/polypropylene composites (Duncan's multiple range tests are given in the parentheses)

The results of other researcher indicated that although boric acid significantly improved the flame retardancy of the composites, it caused a slight decrease in tensile strength. This reduction was attributed to the weakened interfacial bonding between the wood particles and the polymer matrix due to the presence of boric acid (Ünal et al., 2023). Tensile strength of glass fiber-reinforced epoxy composite plates by adding boric acid to the epoxy in different ratios (0, 0.5, 1, and 1.5% by weight) revealed that the highest tensile strength was obtained from the 0.5% BA-added specimens, with a 24.78% increase compared to the 0% BA-added specimens. However, as the BA ratio increased beyond 0.5%, the tensile strength decreased. The study concluded that while a 0.5% addition of boric acid improved the tensile strength, higher concentrations led to a reduction in mechanical properties due to interlayer delamination and fiber/matrix failure (Örçen and Bayram, 2024).

It should be noted that in Figures 4-9, different letters in red and blue colors indicate significance at the 5% level within undecayed and decayed samples separately, while different letters in black color inside parentheses indicate significance at the 5% level for comparisons between undecayed and decayed samples.

3.6 Water and thickness swelling resistance

The results of statistical analysis (Table 2) indicated that pretreating wood flour with a 1% boric acid solution (BA-PT-WPC) enhances long-term water resistance, particularly under decay conditions. This improvement is likely due to better interfacial bonding and reduced fungal degradation pathways. In contrast, incorporating boric acid during blending (BA-T-WPC) shows limited effectiveness over prolonged exposure. These findings align with those of Baysal et al., (2007), who reported that pretreating wood with a boric acid and borax mixture before polymerization improved water resistance and decay durability of WPCs. The study found that such pretreatment reduced water absorption and enhanced resistance against decay fungi, supporting the notion that pretreatment methods are crucial for long-term performance. However, other studies present differing perspectives. For instance, Kartal et al., (2007) observed that wood specimens treated with boron compounds followed by heat modification exhibited increased water absorption due to the hygroscopic nature of boric acid. This suggests that while boric acid can enhance certain properties, its hygroscopicity may counteract benefits in water resistance under specific conditions. Additionally, Zhang et al., (2021) investigated borated wood-polycarbonate biocomposites and found that while boric acid improved fire retardancy, it also led to increased water absorption. The study attributed this to the hydrophilic nature of lignocellulosic fibers, which absorb moisture and potentially weaken the fiber-polymer interface. These contrasting findings highlight the complexity of boric acid's role in WPCs. While pretreatment methods like BA-PT-WPC can enhance long-term water resistance, factors such as the hygroscopic nature of boric acid and the type of polymer matrix used can influence outcomes. Therefore, optimizing treatment methods and considering the specific application environment are essential for achieving desired performance in WPCs.

Table 2. Water absorption (WA) of the untreated and treated composites

Decayed WPC	Time (h)	Mean ± Std. Deviation	Undecayed WPC	Time (h)	Mean ± Std. Deviation
UT-WPC	2	0.43 ab* ± (0.25)	UT-WPC	2	1.39 e ± (0.15)
BA-T-WPC	2	0.35 a ± (0.01)	BA-T-WPC	2	1.30 e ± (0.08)
BA-PT-WPC	2	0.57 b ± (0.04)	BA-PT-WPC	2	1.21 de ± (0.03)
UT-WPC	24	0.98 c ± (0.03)	UT-WPC	24	2.27 g ± (0.12)
BA-T-WPC	24	1.02 cd ± (0.03)	BA-T-WPC	24	2.15 g ± (0.04)
BA-PT-WPC	24	0.97 c ± (0.04)	BA-PT-WPC	24	1.89 f ± (0.04)
UT-WPC	1000	3.67 h ± (0.15)	UT-WPC	1000	6.26 k ± (0.38)
BA-T-WPC	1000	4.31 i ± (0.11)	BA-T-WPC	1000	6.21 k ± (0.27)
BA-PT-WPC	1000	3.60 h ± (0.07)	BA-PT-WPC	1000	5.48 j ± (0.03)

* Different letters in each column indicate a statistical difference ($p < 0.05$) among the composite groups. Values in parentheses are standard deviation (SD).

The results of statistical analysis (Table 3) indicated that in decayed samples, BA-T-WPC exhibited the lowest thickness sweling (TS) (0.00% ± 0.00), indicating a strong protective effect against moisture uptake due to fungal degradation. In contrast, BA-PT-WPC showed the highest TS (0.43% ± 0.25), possibly due to increased surface area or microvoids caused by dual treatment. For undecayed samples, BA-T-WPC recorded the highest TS (5.09% ± 0.75), while BA-PT-WPC showed relatively lower TS (3.02% ± 0.45) than even UT-WPC (3.39% ± 0.44), suggesting that treatment during manufacture may decrease short-term dimensional stability under non-biological conditions. After 24 hours, TS increased in all samples. In decayed composites, both BA-T-WPC and BA-PT-WPC exhibited higher TS values (3.31% ± 1.00 and 3.64% ± 0.38, respectively) compared to UT-WPC (1.86% ± 0.82), implying that boric acid treatments may increase water affinity or fail to fully protect against degradation-induced moisture penetration. In undecayed samples, however, BA-PT-WPC maintained the lowest TS (3.28% ± 0.55), reinforcing its efficacy under intact, fungal-free conditions. In the long-term immersion test, all samples exhibited a significant increase in TS. BA-T-WPC (4.79% ± 0.55) and BA-PT-WPC (4.76% ± 0.63) showed marginally higher TS than UT-WPC (3.06% ± 0.20) in decayed samples, indicating the limited durability of treatments when subjected to prolonged fungal and moisture exposure. In undecayed WPCs, BA-T-WPC displayed the highest TS (7.24% ± 0.60), followed by BA-PT-WPC (6.30% ± 1.18) and UT-WPC (5.43% ± 0.34), suggesting that boric acid treatments may become less effective over extended periods. Matuana et al., (1998) reported that while chemical modifications can improve short-term water resistance, the benefits often diminish over time, particularly under prolonged exposure to water and fungi. Stark and Berger (1997) demonstrated that untreated WPCs often exhibit less swelling than treated counterparts in the long term, due to degradation of additives or leaching of treatment agents. Clemons (2002) emphasized that preservative treatments may initially improve water repellency, but long-term thickness swelling still occurs due to capillary water uptake through interfacial gaps and surface degradation. Overall, preservative treatments (especially BA-PT) show promise for improving short-term water resistance in WPCs, particularly under non-decay conditions. However, long-term exposure and fungal decay significantly reduce their effectiveness, leading to increased thickness swelling. These results highlight the need for more durable and moisture-resistant treatment systems for WPCs, especially for applications in humid or biologically active environments.

Table 3. Thickness swelling (TS) of the untreated and treated composites

Decayed WPC	Time (h)	Mean ± Std. Deviation	Undecayed WPC	Time (h)	Mean ± Std. Deviation
UT-WPC	2	0.17 a*± (0.12)	UT-WPC	2	3.39 c ± (0.44)
BA-T-WPC	2	0.00 a ± (0.00)	BA-T-WPC	2	5.09 e ± (0.75)
BA-PT-WPC	2	0.43 a ± (0.25)	BA-PT-WPC	2	3.02 c ± (0.45)
UT-WPC	24	1.86 b ± (0.82)	UT-WPC	24	3.90 cd ± (0.37)
BA-T-WPC	24	3.31 c ± (1.00)	BA-T-WPC	24	5.17e ± (0.77)
BA-PT-WPC	24	3.64 c ± (0.38)	BA-PT-WPC	24	3.28 c ± (0.55)
UT-WPC	1000	3.06 c ± (0.20)	UT-WPC	1000	5.43 e ± (0.34)
BA-T-WPC	1000	4.79 de ± (0.55)	BA-T-WPC	1000	7.24 g ± (0.60)
BA-PT-WPC	1000	4.76 de ± (0.63)	BA-PT-WPC	1000	6.30 f ± (1.18)

*Different letters in each column indicate a statistical difference ($p< 0.05$) among the composite groups. Values in parentheses are standard deviation (SD).

3.7 Scanning electron microscope analysis for decayed and undecayed WPC samples

The SEM micrographs illustrate the surface morphology of six different decayed and undecayed wood-plastic composite (WPC) samples (Figure 10). The Figures 10a, 10b, and 10c (top, left to right) shows decayed samples, while the Figures 10d, 10e, and 10f (bottom, left to right) shows undecayed ones. The decayed untreated WPC (UT-WPC) (10a) exhibits severe degradation, with visible cracks, voids, and disrupted fiber-matrix bonding, indicating high susceptibility to biological decay. The decayed BA-treated WPC (BA-T-WPC) (10b) shows moderate degradation, suggesting that BA-treatment improved resistance but was not entirely effective. The decayed BA-pre-treated WPC (BA-PT-WPC) (10c) presents the least damage, retaining a relatively intact and compact structure, confirming the effectiveness of full treatment in enhancing decay resistance. In contrast, the undecayed samples demonstrate significantly better structural integrity. The untreated WPC (UT-WPC) (10d) already shows some surface roughness and porosity, while the BA-treated (BA-T-WPC) (10e) and BA-pre-treated WPC (BA-PT-WPC) (10f) show progressively smoother and denser morphologies, indicating improved compatibility and bonding between wood fibers and polymer matrix due to the BA-treatment processes. These observations confirm that BA-treatments enhance the durability and microstructural stability of WPCs, especially under decay fungus.

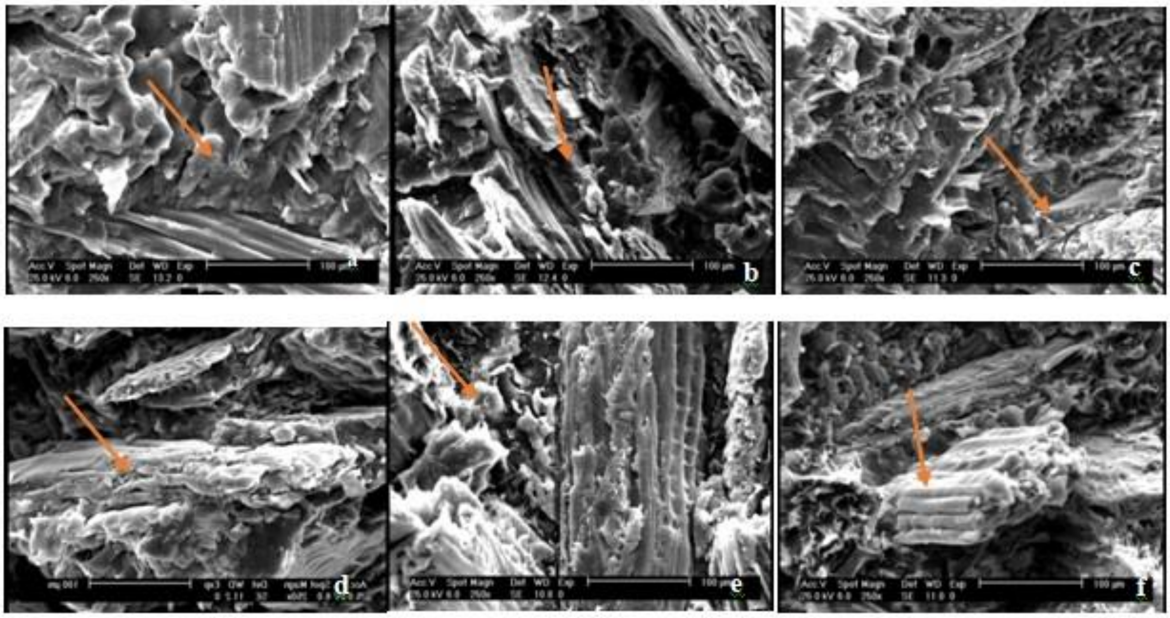

Figure 10. SEM micrographs of surface fracture of weight loss (decayed) and tensile (undecayed) samples with 100 µm magnifications. (a), denote the decayed UT-WPC; (b), denote the decayed BA-T-WPC; (c), denote the decayed BA-PT-WPC. (d), denote the undecayed UT-WPC; (e), denote the undecayed BA-T-WPC; (f), denote the udecayed BA-PT-WPC.

4 Conclusions

- This study demonstrates that boric acid treatment can significantly enhance the mechanical properties and decay resistance of wood flour/polypropylene composites. Both in-process powder addition and aqueous pre-treatment methods improved the composites' strength and durability, with BA-treated specimens showing better performance after fungal exposure.
- BA-T-WPC exhibited the highest flexural strength (50.77 MPa) and modulus (3473 MPa), while BA-PT-WPC demonstrated superior tensile modulus (4563 MPa) and impact strength (49.40 J/m).
- SEM images show that boric acid deposits on wood fibers increase surface area but may weaken polymer bonding. Fiber pull-out and holes indicate poor fiber-matrix adhesion, especially in pre-treated composites. Overall, boric acid treatment presents a promising approach to develop more durable and mechanically robust WPCs for wood-plastic applications.

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Author Contributions
Seyyed Khalil HosseiniHashemi: Creating the research idea, writing the article, performing the statistical operations, **Alireza Badritala**: conducting the laboratory work, taking the measurement data, **Maliheh Akhtari:** Analysis and interpretation of data, writing the article.

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Conflict of interest
We confirm that there is no conflict of interest.

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Mobilya ve Ahşap Malzeme Araştırmaları Dergisi
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Application of wood plastic composite in the construction sector

Beytullah Başeğmez*

ABSTRACT: As with all products, minimizing the negative environmental impact of building materials is crucial. Wood-plastic composites (WPCs) are a promising alternative and sustainable material to conventional materials, contributing to ecological efficiency. This innovative composite, combining thermoplastics and natural fibers, benefits from the low density, cost-effectiveness, and workability of wood, while the thermoplastic component prevents moisture ingress and biological attacks. Recycled thermo-plastics are also used in the production of this composite, thus developing circular economy. Wood fibers or powder can be sourced from waste generated during the manufacturing processes of lumber and furniture manufacturers. In window applications, various polymers can be used in the composite mixture, with PVC being widely accepted. The most common manufacturing method is extrusion although injection and molding techniques are also utilized. WPCs may contain 30% to 60% wood particles, with a 50:50 wood-to-plastic ratio being most common. The increasing adoption of WPCs is expected to significantly reduce the use of petroleum-based polymers. As a result of this study, WPC, largely unknown and used minimally in Türkiye, will become widespread and accepted in the construction sector.

Keywords: Composite, Wood, Construction, Plastic, Waste

İnşaat sektöründe ahşap plastik kompozitin uygulanması

ÖZ: Her üründe olduğu gibi yapı malzemelerinde negatif çevresel etkinin minimize edilmesi önemlidir. Ahşap plastik kompozitler (APK), konvansiyonel malzemelere alternatif ve sürdürülebilir malzeme olarak, umut verici bir seçenektir; ekolojik verimliliğin artırılmasına katkı sunar. Termoplastikler ve doğal lifleri (odun vd.) bütünleştiren bu yeni kompozit, odunun düşük yoğunluğu, düşük maliyeti ve işlenebilirlik özelliklerinden faydalanırken; termoplastik bileşen, ürüne nemin girmesini ve biyolojik saldırıyı engeller. Geri dönüştürülmüş termoplastikler de bu kompozitin üretiminde kullanılır, böylece döngüsel ekonomi gelişir. Ahşap lifleri/tozu, kereste ve mobilya üreticilerinin gerçekleştirdiği imalat süresince ortaya çıkan atıklardan elde edilebilir. Pencere uygulamalarında, kompozit karışımda çeşitli polimerler tercih edilebilmekle birlikte PVC kabul görmüştür. Malzemenin en yaygın üretim yöntemi, istenen şekle ekstrüde etmektir, ancak enjeksiyon ve kalıplama da kullanılır. Ahşap-plastik kompozitler (APK), %30'dan %60'a kadar ahşap parçacıkları içerebilir, yaygın şekilde optimum oran olarak %50-%50 uygulanmıştır. Ahşap plastik kompozitler çevre dostu yapılar için giderek daha cazip bir seçenek haline gelmektedir. Bu malzeme kullanımının gelecekte daha da yaygınlaşmasıyla petrol bazlı polimerlerin kullanımının azalmasına büyük bir etki yapacağı muhakkaktır. Bu çalışma sonucunda, Türkiye'de çok sınırlı uygulamada kullanılmış, yeterince tanınmayan APK'nın yaygınlaşarak inşaat sektöründe kabul görmesi hedeflenmektedir.

Anahtar kelimeler: Kompozit, Ahşap, Yapı, Plastik, Atık

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1 Introduction

The use of natural resources and environmental impacts has become as important as traditional evaluation criteria such as quality and cost in decision-making processes with the increasing awareness of environmental problems. In this context, the concept of sustainable production has become increasingly important to ensure efficient and long-term use of natural resources (Hauschild et al., 2005). Minimizing negative environmental impact is very important as it should be in any product, especially for building materials which are the focus of this study. In recent years, the demand for sustainable and durable building materials in the construction sector has increased significantly. Wood-plastic composites have emerged as a promising alternative to traditional materials such as wood, metal and plastic.

Composite materials are materials formed by combining two or more identical or different types of materials to integrate their best properties into a new and unified material (Şahin, 2000; Clyne & Hull, 2019). A new class of composites has emerged that integrates thermoplastics with natural fibers (such as wood). This innovative composite takes advantage of the low density, low cost, UV resistance, and workability of wood, while the thermoplastic component facilitates flow during melting processes and acts as a barrier to prevent moisture intrusion and biological attacks (Harper & Wolcott, 2004). Wood-plastic composites (WPCs) are composite materials formed by combining wood fibers and/or wood dust with thermoplastics such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), polystyrene (PS), or polylactic acid (PLA) through chemical additives (Figure 1). Recycled thermoplastics can also be used in the production of wood-plastic composites (Bal, 2023; Stark, 2001; Ratanawilai & Srivabut, 2022; Leu et al., 2012; Ashori & Nourbakhsh, 2009; Avcı, 2012). The predominant thermoplastic material used in WPC production is polyethylene (Hamel et al., 2013). Wood particles provide structural reinforcement to the product (URL-1, 2024), thereby combining the advantages of wood and plastic materials. The use of wood dust in thermoplastic composite production is attractive due to its low cost, low density, minimal wear during production, abundance, and biodegradability (Mengeloğlu & Karakuş, 2008). WPC material finds application in various fields utilizing products from both the wood and plastic industries, with its usage areas expanding every day. Each application of wood-plastic composites in different fields is an effective way to enhance ecological efficiency. This material class, which has many subtypes, is commonly referred to as "WPC" derived from the initials of "Wood Plastic Composite."

Figure 1. Wood powder and polymeric raw materials in granular form (URL-2, 2024; URL-3, 2024).

In the 1980s, a company in the United States produced wood-plastic composites (WPC) by incorporating 50% wood powder into polyethylene (PE). This composite material was used to manufacture and sell industrial products such as garden furniture, tables, and decking/terrace materials. During the same period, WPC was produced by mixing polypropylene (PP) and wood powder in equal proportions, leveraging extrusion techniques for use in the interior cabin components of automotive sector products. The demand, need, and areas of application for WPC materials in Türkiye and many parts of the world have been increasing over time

(Şahin, 2023). In Asia, the primary WPC markets have been Japan, South Korea, and China since the 1990s (Gardner and Han, 2010). Activities carried out over recent decades have significantly developed the market.

In Figure 2, the trend of wood-plastic composite (WPC) material production volume in the American and European markets can be observed during the first quarter of the 21st century. Germany leads the way in Europe in this regard (Eder, 2010). Additionally, the figure provides insights into the sales performance of WPC in various markets and expectations for the coming years. The WPC market is expected to maintain its growth trajectory, reaching an estimated global value of approximately $12 billion by 2028 with a compound annual growth rate (CAGR) of around 10% (URL-4, 2024).

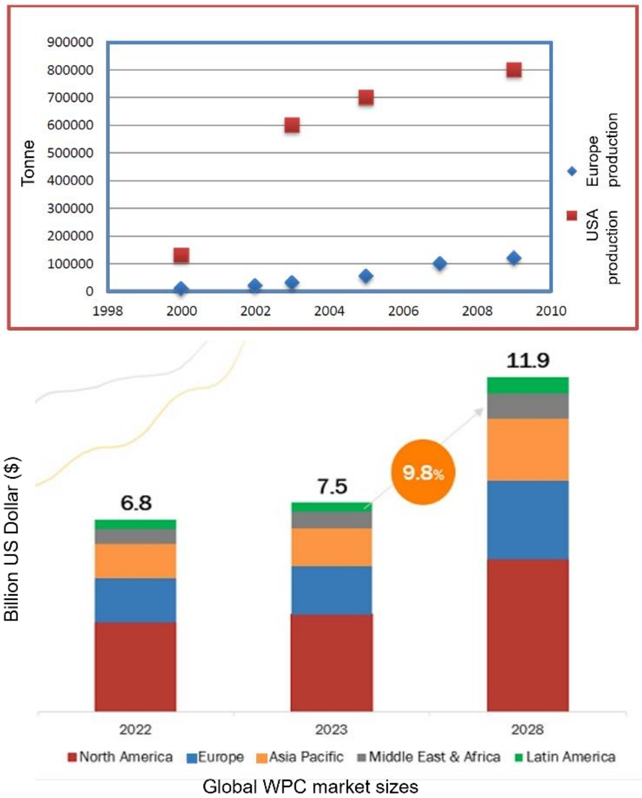

Figure 2. (a) The trend of wood plastic composite material production volume in the US and European markets (Eder, 2010). **(b)** Sales performance and future expectations in various markets (URL-4, 2024).

In Türkiye, the majority of the WPC sector is dedicated to outdoor flooring, while a significantly smaller portion is used primarily in applications such as pergolas. The purpose of this article is to use WPC as a building material. The market volume of the Turkish wood-plastic composite sector is approximately ten thousand tons. The WPC sector in Türkiye is expected to continue growing, driven by the continuously increasing demand in the construction industry (URL-5, 2024). Some of the companies producing wood-plastic composites in Türkiye are as follows: Hekim Board: Exterior wall cladding profiles and panels. Therrawood: Decks, terraces, exterior cladding, fences, gazebos, railings and prefabricated houses. Make WPC: Deck and outdoor flooring. Burdeck: Tiles, profiles, planters and urban furniture (URL-6 – 9, 2024).

2 Usage Areas

Wood-plastic composites (WPC) have found applications in numerous sectors, with the construction industry being the primary area of use. Table 1 presents these application areas. WPC is commonly employed for outdoor decking, terrace and patio flooring, railings, fences, landscaping timbers, park benches, cladding, exterior siding, prefabricated home panels, window and door frames, trims, and indoor furniture (Stark, 2001; URL-10, 2024; URL-11, 2024). The natural wood appearance of WPC creates a warm and natural ambience while its durable structure ensures long-lasting use. The ability of WPC produced in various colors and textures offers furniture designers a broad creative scope (Figure 4) (URL-10, 2024; URL-12, 2024). When WPC decking is applied around swimming pools (Figure 3), the material's anti-slip property can help prevent potential injuries compared to ceramic-based products such as marble, tiles, or granite, especially when individuals walk barefoot on wet surfaces.

Figure 3. Wood plastic composite application as poolside/deck ground (URL-13, 2024).

Figure 4. Wood plastic composite plate for modern modular kitchen cabinet (URL-14, 2024).

WPC cladding is used for both exterior and interior wall coverings (Figure 5). It adds aesthetic appeal to structures while providing insulation. WPC cladding products are light-weight, easy to install, and contribute to enhancing the energy efficiency of the buildings to which they are applied. WPC is widely used for terraces, balconies, railings, and stairs of residential and commercial structures. Providing sufficient strength and safety, these wooden-looking railings are resistant to moisture, do not rot, do not splinter, do not bend and are quite durable. WPC is increasingly utilized in the production of outdoor furniture, such as benches, tables, and chairs. WPC is among the ideal choices for outdoor applications, considering its durability and resistance to moisture. Furthermore, WPC furniture offers a wide range of design and color options, enhancing aesthetic versatility. Its use for these purposes is also applied in Türkiye. In addition to outdoor applications, WPC is also used for interior applications such as ceiling panels, wall panels, and baseboards. Its ability to be molded into various shapes and finishes makes WPC suitable for decorative purposes (URL-12, 2024). Moreover, wood-plastic composite parts are frequently used in the production of sports and musical instruments. For instance, laminated skis, golf equipment, hockey sticks, and baseball bats are commonly manufactured using wood-plastic composites (Leu et al., 2012; Bayram, 2024).

Figure 5. Application of wood-plastic composite as an exterior building cladding (URL-15, 2024).

Table 1. Application areas of wood plastic composite (Liukko et al, 2007).

Sector	End-Product Market Applications					
Construction	Exterior cladding	Door frames and components	Window frames components	Barge boards	Pre-treated floorboards	
	Ceiling products	Roof covering	Stairs	Timber	Porch	
Interior Architecture / Surfaces	Railings	Curtains and blinds	Channel connections	Flooring	Decorative profiles	Interior panels
	Kitchen cabinets	Parquet	Office furniture	Shelves	Baseboards	Sound insulation coatings
Automotive	Interior panels	Door and chest linings	Cable channels	Luggage racks	Spare tire covers	Trailer floors
Garden / Outdoor	Flooring	Garden sheds, huts, etc.	Garden furniture	Fences and fence connections		
	Park benches	Children's playground equipment	Playground flooring			
Industrial / Infrastructure	Railings	Industrial packaging	Marine piles and partitions	Pallets and crates		
	Quays, piers	Trash cans	Signs			

WPC can be utilized in the production of window and door frames, balancing adequate strength properties with aesthetic considerations. These frames (Figure 6) are resistant to direct exposure to water or liquids, moisture, termites, and decay. They offer good insulation properties, contributing to the energy efficiency of buildings (URL-12, 2024). For window applications, PVC is commonly used as the polymer component in the composite mixture, though other thermoplastics can also be employed. PVC integrated with wood powder is gaining prominence due to its balanced thermal stability, moisture resistance, and hardness. Other attractive parameters include low maintenance and repair costs, absence of cracks and splinters, and high durability. In addition to solid rectangular profiles, window frame designs may also incorporate complex hollow and grooved profiles to reduce costs and weight while maintaining structural integrity. These specialized profiles can be tailored for frame production (Bala, 2018). Andersen Corp. established a PVC-based WPC window line years ago, securing its position in the window market. The company also produces innovative fiberglass-framed window solutions (URL-16, 2024).

Figure 6. Wood plastic composite (WPC) window frame and its profiles (URL-17, 2024).

3 Material Properties

Wood-plastic composites (WPCs) are highly resistant to abrasion, decay, and deterioration (Stark, 2001). WPCs demonstrate strong resistance to both water and moisture (URL-10, 2024). An additional advantage over wood is the material's ability to be extruded or molded into almost any desired shape. WPCs have great machinability and can be shaped using traditional woodworking tools. Since WPCs are often made using recycled plastics and waste products from the wood industry, they are considered a sustainable material. This is also important in the context of waste management (Stark, 2001). Their production helps reduce deforestation and plastic waste. They are an environmentally friendly material. At the end of their lifespan, WPCs can be shredded and reprocessed into new products (URL-12, 2024). Additionally, they are resistant to bacterial growth due to their hygienic properties. They also do not conduct flames with high safety standards (URL-18, 2024).

Wood-plastic composites (WPCs) are known to exhibit non-linear viscoelastic behavior similar to unfilled polymers. This means that their mechanical responses depend on variables such as stress, temperature, and time (Hamel et al, 2013). Due to the addition of organic matter, WPCs are typically processed at much lower temperatures compared to traditional plastics during extrusion and injection molding. WPCs begin to burn at temperatures around 200°C. Since they melt at lower temperatures, the energy required for manufacturing is reduced. As a rule, the higher the wood/plastic ratio, the lower the melting temperature (URL-1, 2024). It has been observed that WPC materials produced by extrusion have a lower fire risk compared to those made by other manufacturing methods, considering factors like ignition, progression of burning, etc. (Lopez et al., 2022). There are several strategies to enhance the flame resistance of WPCs, which can be broadly categorized into two main approaches. The first involves incorporating flame retardants into the wood-plastic polymer mixture during compression, injection, or extrusion processes. The second strategy involves pre-treating the wood particles with liquid flame retardants through impregnation, followed by combining the particles with polymers using traditional processing methods (URL-11, 2024).

The performance of wood-plastic composites (WPCs) depends on various factors, including the microstructure of the composite, void content, wood-matrix stress transfer efficiency, particle morphology, and the chemical composition of lignocellulose (Hung et al., 2017). WPCs may contain between 30% and 60% wood particles, which significantly reduces the dependence on petroleum-based plastic materials. The wood fibers or dust (sawdust) used in WPC production are typically waste materials generated during lumber processing by manufacturers. These matters are processed to create a more cost-effective and stronger reinforcement product. The type, size, and concentration of wood particles in the composite formulation can be adjusted to achieve different properties (URL-1, 2024; URL-11, 2024; Hung et al., 2017). The effects of wood species on the water absorption, biological degradation, metal corrosion, and color changes of WPCs due to outdoor exposure have been studied and reported. It is known that wood dust from various species can be used as a raw material for WPC production (Fabiyi & McDonald, 2010). Similarly, the selected wood species will influence the final color of the product. Commonly used wood species in WPCs include pine, oak, and maple. Cost is a key factor in these choices. Pine fillers tend to produce lighter-colored products compared to hardwood fillers (URL-1, 2024; URL-11, 2024; Hung et al., 2017).

Research and development activities related to wood-plastic composites (WPCs) primarily focus on enhancing raw materials and optimizing production processes. Examples of studies in this area include the testing of different wood powder or fiber sizes, using various wood species, using wood powder resulting from the break-up of end-of-life wood materials, utilizing lignocellulosic annual plants, and experimenting with different polymer types and mixture ratios (Rowell et al., 1997).

The inclusion of wood fibers in plastics improves the bending and tensile properties of the resulting composites compared to pure plastics (Hung et al., 2017; Fabiyi & McDonald, 2010). Using finer wood powder (smaller than 125 µm) can enhance the tensile and flexural strength of WPCs and reduce swelling caused by water absorption. Experimental studies have proven that using larger particle-sized wood powder increases moisture absorption and swelling in specific proportions (Leu et al., 2012). The bond between wood and plastic is typically weak due to the hygroscopic nature of wood and the hydrophobic properties of plastic, leading to challenges in stress transfer between the wood and plastic phases. To address this issue, compatibilizers are employed to improve the stress transfer between wood and plastic and form interfacial bridges between the two materials (Avcı, 2012; URL-11, 2024). Maleic Anhydride Polypropylene (MAPP) is a commonly used compatibilizer in WPCs to enhance the compatibility between polypropylene (or other thermoplastics) and wood dust, thereby improving the microscopic interfacial bond between wood particles (fibers) and the plastic matrix (Xue et al., 2007). The optimal concentration of the compatibilizer (MAPP) and lubricant (zinc stearate) in WPCs is 3% (Leu et al., 2012). Adding the right amount of compatibilizer can improve mechanical properties and significantly reduce swelling (Leu et al., 2012; Adhikary et al., 2008). Studies have verified that MAPP usage prevents the formation of irregularly shaped micro-voids or defects in the WPCs (Adhikary et al., 2008). However, excessive use of compatibilizers and lubricants can cause significant swelling due to the formation of bonds between the molecules of the additives, which in turn negatively impact mechanical properties. It has been found that maintaining the wood content at 50% or less provides the best mechanical properties. Wood content exceeding 50% leads to a decrease in both the physical and mechanical properties of WPCs (Leu et al., 2012). As the proportion of wood powder increases, the density of the composite also increases (Avcı, 2012). The dimensional stability and strength properties of wood-plastic composites can be improved by increasing the polymer or compatibilizer binding additives content (Adhikary et al., 2008).

When examining the stress-strain behavior of HDPE-wood powder composites under tensile loading, it was observed that the addition of wood powder increases the stiffness of the composite material while the strain at break decreases. As the wood powder content increases, the yield and tensile strength, as well as the tensile modulus, increase while the material becomes less ductile, meaning it becomes more brittle and durable. The elasticity modulus (E) increases continuously as the wood powder content increases in HDPE WPC composites. On the other hand, composites with a higher HDPE content exhibit greater ductility and a higher breaking strain. Composites with the addition of the MAPP compatibilizer have higher bending strength compared to unmodified composites (Adhikary et al., 2008).

When a wood-plastic composite material is in direct contact with water for prolonged periods, it negatively impacts the material's mechanical properties. Over time, the wood powder absorbs water and tends to swell, leading to the formation of micro-cracks, and the bond between the plastic and wood weakens (Ratanawilai & Srivabut, 2022; Lopez et al., 2022). As the wood dust (fiber) content increases, more water absorption points are formed, causing more water absorption, which accelerates the infiltration of water through capillary effect. (Ashori & Nourbakhsh, 2009; Adhikary et al., 2008). Experiments using waste wood-derived wood powder and HDPE-based hot-pressed WPCs have shown that using smaller wood powder particles improves the material's water absorption and swelling properties (Chen et al., 2006). The addition of MAPP (maleic anhydride polypropylene) as a compatibilizer is known to reduce water absorption. In WPCs with MAPP, the parameters related to the wood powder-polymer ratio are less variable compared to those without MAPP WPC composites. MAPP also reduces the effects of water absorption and swelling, allowing changes in the wood content to have a minimal effect on the overall properties of the WPC (Adhikary et al., 2008; Markarian, 2005).

WPC products require less maintenance than natural wood. They are more economical and easier to maintain as they do not require painting, varnishing or sealing. They are easy to clean and can withstand harsh weather conditions without deteriorating (URL-12, 2024). Issues such as cracking and color degradation, which are seen in PVC window frames due to temperature and load, don't occur in WPC window frames. These specifications make them ideal for window frames as they are constantly exposed to external conditions. Table 2 compares wood, plastic and wood-plastic materials in terms of various properties.

When comparing products made from WPC materials to those made from Medium-Density Fiberboard (MDF), a material considered indispensable in the wood industry, the following conclusions can be drawn:

- Both WPC and MDF products have values ranging from 20 to 40 MPa in terms of tensile strength (Avcı, 2012; Gardner & Han, 2010; Xue et al., 2007; URL-19, 2024). WPC is highly durable and weather-resistant, making it an ideal choice for outdoor or wet areas. MDF exhibits lower resistance to moisture and decay and may require maintenance.
- WPC panels can be assembled using a clip and rail system, making installation and removal easier. MDF panel installation is done by nailing or gluing them to the wall.

- WPC can be produced in various colors and textures, including wood patterns, while MDF can be painted or veneered to create different surfaces.
- WPC is more expensive than MDF, but its superior features outweigh this disadvantage. The cost per square meter of WPC is approximately two to three times that of MDF (URL-19, 2024). Its low maintenance requirements and extended lifespan render it a cost-effective choice in the long run (URL-12, 2024).
- While MDF swells when liquid or water seeps in, WPC is waterproof. However, it has been shown that WPC still absorbs a small amount of moisture, but at a much slower rate compared to solid wood.
- MDF can be used for up to 10 years, while WPC can last for 50 years.
- While WPC can be easily shaped into different shapes, MDF cannot be easily transformed into different shapes.
- Some harmful chemicals and substances may be used in the production of MDF. However, no chemicals or hazardous substances are used in the production of WPC (URL-11, 2024; URL-19, 2024).

Table 2. Comparison of wood plastic composite general material properties with wood and plastic (Bala, 2018).

Material properties	Wood plastic composite	Wood	Plastic
Resistance to sunlight and aging	+++	+	++
Natural wood appearance	+++	++++	+
Moisture resistance	+++	+	+++
Resistance to water absorption	+++	+	++++
Resistance to biological pests (insects)	++++	+	++++
Ease of machinability	++++	++++	+
Ease of maintenance	+++	+	++
Nailing ability	++	+++	+
Low expansion ratio	+++	+++	+

A wide range of waste produced in various industries can be used in the production of wood-plastic composites (WPC), thus promoting the development of a circular economy. The source of the recycled plastics used in recycled WPC is typically municipal solid waste facilities. In addition to plastic bottles, containers, bags, accessories, cups, packaging materials, etc., automotive industry waste can also be used as raw materials (Ramli, 2024). The properties of waste plastics are similar to those made from original materials. Many experiments have shown that there is only a minor change in the mechanical properties of recycled polyethylene compared to the original PE (Ashori & Nourbakhsh, 2009, Adhikary et al., 2008). Furthermore, the granules of recycled plastics are cheaper compared to pure plastic granules (Adhikary et al., 2008). The evaluation of recovered plastics and the development of new value-added products are becoming increasingly important (Ashori & Nourbakhsh, 2009).

4 Production Methods

The most common manufacturing method for wood-plastic composites (WPCs) is extrusion, although injection molding and compression molding are also employed (Stark, 2001 & Ratanawilai & Srivabut, 2022; Hamel et al., 2013; URL-12, 2024; Kumari et al., 2007). In terms of water resistance and mechanical properties, materials produced through injection molding and extrusion molding have been found to perform better than those produced via compression molding (Kumari et al., 2007). Additives such as colorants, coupling agents, UV stabilizers, blowing agents, foaming agents, and lubricants help tailor the final product to its target application. Coupling agents, used at concentrations ranging from 3% to 5% of the mixture, improve interfacial adhesion between the plastic matrix and wood powder filler by creating a strong bond. These additives also facilitate optimal processing conditions. WPCs can be molded to incorporate intricate wood grain patterns. Extruded WPCs can be fabricated in both solid and hollow profiles (Figure 7) (Stark, 2001; Ratanawilai & Srivabut, 2022; Leu et al., 2012; URL-11, 2024; URL-12, 2024). From a manufacturing perspective, processing WPCs is quite similar to processing conventional petroleum-based plastics. As the material behaves similarly, large-scale investments in new machinery and equipment are generally unnecessary (URL-1, 2024).

Figure 7. Wood plastic composite (WPC) profiles (URL-20, 2024).

The performance of WPCs is significantly influenced by the particle size of fillers; therefore, wood powders are classified using sieves. Different sieve mesh sizes ensure that the wood powder particles meet the desired dimensions. The obtained wood powders are subjected to a drying process in drying ovens at 100±5 °C until fully dried (Figure 8). Subsequently, the polymer and wood powder are blended with a very small amount of paraffin-wax adhesive in a high-speed mixer to achieve a homogeneous mixture. The mixture is heated in an extruder to a temperature slightly below the combustion point of the materials (Şahin, 2023). The temperature is maintained between 170-200 °C during the extrusion process (Ratanawilai & Srivabut, 2022; Kumari et al., 2007). The molten mixture exiting the extruder is cooled in water and then converted into particles using a crusher machine. The dried particles, which have zero moisture, are processed into the final product through plastic injection molding (Şahin, 2023). Since processing variables have a critical impact on the final product, technological parameters require precise control. For example, extremely low or high cylinder temperatures, excessive high screw speed, or injection speed can result in surface defects in the composites (Lopez et al., 2022). The primary role of lubricants in the WPC processing cycle is to improve the wettability of wood powder and enhance slippage between wood and plastic particles (internal lubrication), and/or ensure the smooth and homogeneous manufacture of the product in the extruder (external lubrication) (Leu et al., 2012). Specially engineered extruders tailored for the direct extrusion of WPCs are available, and research and development activities in this field are ongoing (Markarian, 2005). WPCs can be painted or colored to suit nearly any design scheme (URL-11, 2024). After obtaining profiles with a consistent cross-section and several meters in length through the extrusion process, the material exhibits an appearance similar to plastic. The profiles are then processed in a unit where thermoplastic wood texture is applied, brushed, or sanded on the desired surfaces, achieving a perfect wood-like appearance (Figure 8) (Bayer et al., 2017).

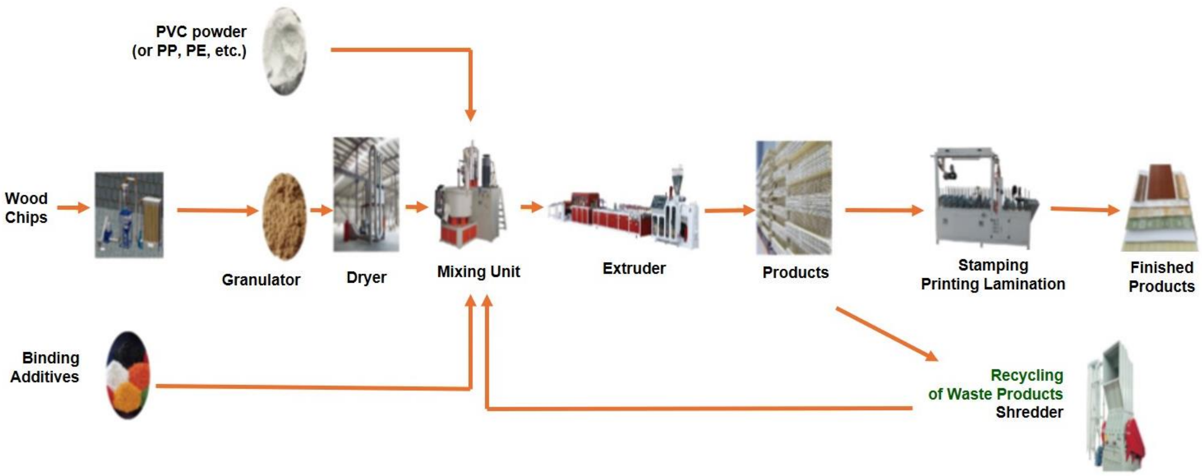

Figure 8. Wood plastic composite (WPC) production process (URL-21, 2024).

5 Conclusion and Suggestions

Wood-plastic composites can be applied in various fields where both wood and plastic sector products are used, and their application areas are expanding every day. The low cost of wood dust, its low density, minimal wear during production, abundant availability, and its biodegradability in nature make it an attractive material for use in thermoplastic composite production. Each application in different fields is an effective way to enhance ecological efficiency. The use of recycled thermoplastics is considered in the production of wood-plastic composites (WPC). The thermoplastic material primarily used in WPC production is polyethylene. However, PVC is commonly preferred for window frames, and the utilization of recycled PVC can also be considered. In this context, recycling existing PVC window frames for use in WPC production may be possible.

- Wood-plastic composites (WPC) have found application area in many sectors, particularly in the construction industry. In Türkiye, a large portion of the WPC sector is dominated by outdoor flooring (decking), while a much smaller segment is particularly used in applications such as pergolas. The WPC industry is expected to continue growing with the continuously increasing demand in the construction sector. In recent years, WPC has begun to partially replace some traditional and new engineered wood products. The use of petroleum-based polymers (plastics) will certainly decrease significantly as the use of WPC materials becomes more widespread in the future. Additionally, WPCs are more cost-effective compared to polymer types. Supporting and prioritizing research and development of WPC materials, which continue to improve and grow, is crucial for the wood and plastic industries.
- Wood-plastic composites (WPC) can contain wood particles ranging from 30% to 60% which significantly reduces dependence on petroleum-based plastic materials. Keeping

the wood content at 50% or lower has provided the best mechanical properties. WPC and MDF products have been found to have similar tensile strength, with values ranging between 20 and 40 MPa. Wood fibers/dust (sawdust) can be obtained from waste materials produced during the manufacturing process of lumber and furniture producers. The type, size, and concentration of the wood particles in the composite formulation can be adjusted to achieve different properties. It is known that wood dust from many species can be used as raw material for WPC production. Incorporating wood fibers into plastics improves the bending and tensile properties of the resulting composites compared to pure plastics. This is also significant for the preservation of Türkiye's forest resources.

- The most common production method for wood-plastic composites is extrusion, where the material is extruded into the desired shape; however, injection molding and compression molding are also used. In terms of water resistance and mechanical properties, materials produced through injection molding and extrusion molding have been found to perform better than those produced by compression molding. Additives such as colorants, binders, UV stabilizers, blowing agents, foaming agents, and lubricants help tailor the final product to the target application requirements. The optimum concentration of maleic anhydride polypropylene (MAPP) as a binder in WPCs is 3%. Adding an appropriate amount of binder can improve mechanical properties and significantly reduce swelling. Products can be created in both solid and hollow profiles with the extrusion method, which is also preferred in window frame production. Since the material behaves similarly, large-scale investments in new machinery and equipment are not required.
- Research and development activities related to WPC (Wood-Plastic Composites) primarily focus on improving raw materials and production processes. Ongoing and upcoming studies include various wood dust or fiber sizes, testing various types of wood, using wood dust obtained from the disintegration of expired wood materials, and using various polymer types and mixing ratios. The quality of WPC products has been continuously improved with the advancement of WPC production technology and deficiencies encountered in production and use have been eliminated. The mission of the WPC sector in Türkiye and the world is to ensure that WPC is used more widely and as a higher quality building material, its performance is fully utilized and better services are provided to the sector.
- The use of WPC, which has become more visible in Türkiye in recent years with its application in open space/plaza arrangements by metropolitan municipalities and in some residential projects, has gained momentum, especially with the increase in construction projects supporting detached living. It is observed that WPC is increasingly incorporated into the architectural designs of sites/residences used in interior spaces, exterior cladding, or landscaping arrangements. This trend is expected to continue growing with the effect of competitive pricing policies and its share in the construction sector is expected to increase.

As a result of this study, the use of wood-plastic composites as an environmentally friendly solution for building materials, particularly window frames in green building projects, is recommended as a sustainable and energy-efficient option in the construction sector. In residential and other buildings, WPCs can be used to create more sustainable homes and provide window frames that align with modern design trends. WPCs will continue to play an important role in window frame production in the future. In this way, the need for aluminium profiles used in existing PVC windows will be eliminated. This material will also fill an important gap in waste management, providing a balanced solution in both performance and aesthetics, solidifying its position in the construction industry.

Author Contribution

Beytullah Başeğmez: Conceptualization, Determination of the methodology, Data curation, Formal analysis, Investigation, Project administration, Visualization, Writing – original draft, Writing – review & editing, Resources, Checking, Validation.

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